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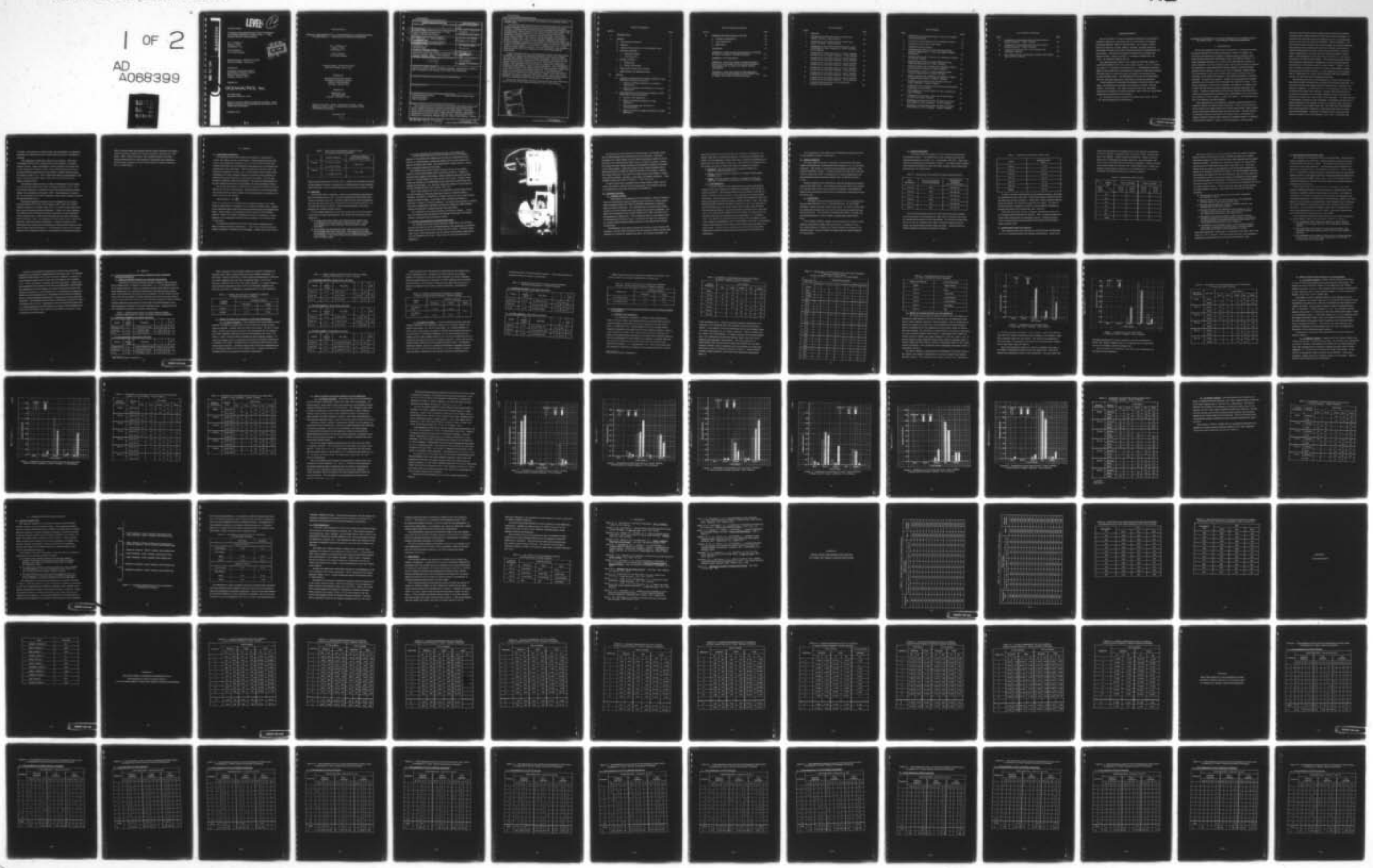

LEVEL II

Technical Report

LUMINANCE REQUIREMENTS AND COLOR APPEARANCES OF COLORED DISPLAYS IN TURBID WATER: I. DARK AMBIENT VIEWING ENVIRONMENTS

W. S. Vaughan, Jr.
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Contract Number: N00014-74-C-0276
Work Unit Number: NR 196-134

Prepared for:

Engineering Psychology Programs
Psychological Sciences Division
Office of Naval Research
Arlington, Virginia 22217

Prepared by:

OCEANAUTICS, Inc.

422 Sixth Street
Annapolis, Maryland 21403

December 1978

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Dark-adapted observers viewed six narrow-band wavelength displays and a white display through two artificially turbid media whose physical and optical properties simulated natural ocean and harbor waters. The source display was a 3-digit fiber optic display optically modified in wavelength by appropriate filters and in size by a reduction lens. The luminance of the display was a continuous variable under the control of the observer. Display CONT'

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luminance was gradually increased by the rotation of a calibrated neutral density wedge.

Ten observers made legibility and color appearance judgments in response to the experimental variations in display size and wavelength, and water turbidity. Observers made judgments about the legibility of the display based on operationally defined changes in the clarity of the fiber optic display, and judgments about color appearance of the display using a forced-choice, color-naming technique and a restricted set of color names: Blue, Green, Yellow, Red and White. Three levels of display legibility were defined, an optimum ('Clear') and a lower and upper boundary ('Minimum' and 'Limit'). Observer permitted the luminance of the display to increase from entirely dark to levels of luminance enabling the display to appear, in sequence, 'Minimum', 'Clear' and 'Limit' legible. At each level of display clarity, i.e., at successively higher display luminances, observer described the color appearance of the display by one or by a combination of two color names from the restricted set.

Values of display luminance were determined for each of the three levels of legibility and these were significantly different as functions of display size and water turbidity, but not of display wavelength. Baseline color appearances of the seven colored stimuli were described in the relatively clear 'Ocean' medium at 'Clear' legibility and at 41' visual angle display size. Shifts in color appearance from the baseline descriptions were determined as functions of water turbidity, display size and luminance. Color appearances of the White and the 608 nm displays varied with water turbidity. Appearance of the 579 nm stimulus varied with display size. Color appearances of several of the wavelength-controlled stimuli varied with increased luminance in the relatively clear 'Ocean' viewing medium: White, 473 nm and 579 nm appeared to increase in saturation; 552 nm and 608 nm shifted toward yellow; the 640 nm wavelength appeared desaturated at the highest luminance.

Conclusions about display luminance requirements and color appearances apply to the case of dark-adapted observers in dark, turbid waters.

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ACKNOWLEDGMENTS

This is the fourth in a series of experiments directed to the problem of underwater displays and conducted under the sponsorship of Engineering Psychology Programs, Office of Naval Research. Dr. Martin A. Tolcott, Director of Code 455, and Mr. Gerald S. Malecki, scientific officer for this program of research have been continuing sources of encouragement and good counsel. The program has further benefitted from the interest and support of CAPT J. Barnes and CDR I. C. LeMoyne of OPNAV 323, and LCDR J. W. Schropp of NAVSEA (00C-3).

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We are pleased to acknowledge the particular contribution of Mr. Allan Slater, Senior Engineer of Emergency Care Research Institute, Plymouth Meeting, Pennsylvania. Mr. Slater designed the test tank, the optical system and the control and recording apparatus used in this as in all previous experiments conducted during the program.

Dr. Kent Boyd advised us regarding the experimental design, and Mr. T. W. Rodes programmed the data analysis.

LUMINANCE REQUIREMENTS AND COLOR APPEARANCES OF COLORED DISPLAYS IN TURBID WATER: I. DARK AMBIENT VIEWING ENVIRONMENTS

I. INTRODUCTION

The present experiment had two primary objectives: to provide data about luminances required of self-luminous displays in order to be legible, and about the color appearance of displays at legible levels of luminance when viewed through water media representing 'Ocean' and 'Harbor' turbidity. An earlier experiment (Vaughan, et al, 1977) used a threshold-like criterion of display legibility; and while threshold values can be used as guides to engineering applications, more operationally-oriented legibility criteria for display luminance can be defined. Carel, et al, 1974, for example, studied display size requirements as functions of several other display variables and characteristics of the viewing environment. They used two definitions of display legibility: 'threshold' and 'comfort'. Display size requirements for 'comfort' legibility were on the order of 20-30% greater than 'threshold' values. In the present experiment, three levels of legibility were defined: an optimum level ('Clear') and both lower and upper boundaries of legibility ('Minimum' and 'Limit'). Luminance requirements for these three criterion levels were determined for six narrow-band wavelengths and a white display at two sizes under two conditions of water turbidity: 'Ocean' and 'Harbor'. All water media were dark, and observers were dark-adapted.

Color appearance was of interest as a potential coding dimension for information transfer via visual displays underwater. While several operational diving systems use colored displays and colored signal lights, little is known about the perceptual experience they convey to the diver. Previous research in underwater viewing environments have studied color or wavelength as a stimulus attribute affecting either detection of submerged targets or legibility of self-luminous displays. Kinney, Luria and Weitzman, 1967 and 1969,

varied the color of painted spheres (both regular and fluorescent paints), submerged them in different bodies of water which ranged in turbidity, illuminated them with both natural and artificial sources, and assessed the accuracy with which the colors were identified. Kinney and Miller, 1974, varied the background against which colored targets were viewed underwater. These studies were concerned principally with visibility enhancement of relatively large objects at ranges near the limits of detection, and their results suggested the colors most and least visible according to type of water. Color appearances of the stimuli were obtained by a color-naming technique in the 1967 and 1969 studies. These results suggested shifts in color appearance attributable to differences in the wavelength-selective transmissivity of the different bodies of water studied. Vaughan, et al, 1977 assessed wavelength variations as an aid to digit legibility at near-threshold levels of display luminance. Color appearances of the displays were not determined; and, given a dark environment and dark-adapted observers, they may have been perceptually achromatic.

The perception of color in air environments is a well-studied research area which provided background for the design of the present experiment. Of particular relevance were findings related to display size, luminance, and duration of exposure. A visual angle of 15' is an approximate minimum size for stable and accurate color judgments. Colored stimuli smaller than 15' visual angle may appear to color-normal observers as they would to an observer with a unique color vision defect, foveal tritanopia. The entire spectrum of wavelengths is reduced to three categories: wavelengths less than 570 nm appear blue/green, those between 570 and 575 nm appear white, and wavelengths beyond 575 nm appear yellow/red. This effect when experienced by color-normal observers in response to small-sized light stimuli is called 'small-area tritanopia'. Differences in display size may also affect the apparent saturation of its color (Burnham, et al, 1967). As display size

increases, and luminance is held constant, the color appears to increase in saturation to a limiting size of 20° visual angle; beyond 20°, the effect is reversed.

Color appearance shifts with intensity of the stimulus. Mid-range wavelengths (520-570 nm), called 'green' at low luminance, are called 'yellow' at high. Longer wavelengths, 590 nm and above, are called 'red' at low intensity and 'yellow' at high. These shifts with intensity define the Bezold-Brücke phenomenon and hold within a moderate intensity range. For example, Smith, et al, 1968, confirmed the effect at approximately 3 and 30 ft-L (10 and 100 cd/m^2); Beare, 1963, did not at 3100 and 7410 mL (9867 and 23586 cd/m^2).

Long-duration exposures have the effect of desaturating colors; greens and reds are more affected than blues and yellows (Burnham, et al, 1967). Long-duration exposures (3 minutes) to very high intensity displays produce bizarre color perceptions (Cornsweet, 1962). These phenomena, however, are not anticipated in the present experiment where maximum display luminance was approximately 60 ft-L.

The present experiment assessed the color appearance of six narrow-band wavelength stimuli and a white stimulus under 'Ocean' and 'Harbor' turbidity conditions, at display sizes of 23', 41' and 82' visual angle and at three levels of luminance defining 'Minimum', 'Clear' and 'Limit' legibility. The method used to describe the observer's perception of color appearance was the forced-choice, color-naming technique first described by Boynton, Schafer and Neun, 1964. The technique has been shown to have consistently high inter- and intra-observer reliabilities. Boynton and Gordon, 1965, demonstrated the sensitivity of the technique in detecting hue shifts in accord with the Bezold-Brücke phenomenon. The technique has been used to assess stimulus size and duration effects on color appearance (Weitzman and Kinney,

1967); to assess foveal vs peripheral location effects (Weitzman and Kinney, 1969); and stimulus intensity and duration interaction effects (Luria, 1967; Kaiser, 1968). Siegel and Siegel, 1971 compared results of the color-naming technique with two other methods of quantifying color appearance and found high consistency at each of three levels of stimulus luminance, 0.01, 1.0 and 100 ft-L.

II. METHOD

A. Turbid Water Simulations

Two artificially turbid water media were prepared as simulations of 'Ocean' and 'Harbor' viewing environments. Similar preparations have been used in prior experiments (Vaughan, et al, 1977 and 1978) concerned with legibility thresholds and with peripheral field effectiveness for detection and identification tasks underwater. Details regarding the materials used, the formulas for preparing the media, etc., can be found in those earlier reports. Essentially the 'Ocean' turbidity simulation consisted of small numbers of relatively large-sized particles in suspension; the 'Harbor', by very large numbers of relatively small-sized particles. The physical characteristics of the two viewing environments are specified by the data contained in Table 1.

The optical characteristic defining the two experimental media was optical density as a function of wavelength. Transmissivity at selected wavelengths was measured with a Beckman Model DK spectrophotometer and transformed to optical density by the formula:

$$\text{Optical Density} = \log \left(\frac{100}{\%T}\right)$$

where %T is the percent of incident light transmitted through a 10 cm path length of turbid water as compared to a 10 cm path of distilled water. Samples of the artificially turbid waters were taken periodically during the experimental trials. Optical density vs wavelength data for each of the five samples taken for 'Ocean' and 'Harbor' simulations are tabled in Appendix A. Also in Appendix A are comparisons with the optical properties of all samples taken in prior years.

In summary, the artificial media used in the present experiment were highly consistent with prior preparations. 'Ocean' was a highly transmissive medium insensitive to differences in wavelength. Between 470 nm and 640 nm,

Table 1. Particle Sizes and Numbers Defining 'Ocean' and 'Harbor' Turbidity Simulations

	Particle Diameter	Estimated Number of Particles per cm^3 Water
'Ocean'	$\bar{X} = 25.7 \times 10^{-6}$m $\sigma = 10.0 \times 10^{-6}$m	4.64×10^{2}
'Harbor'	$\bar{X} = 1.091 \times 10^{-6}$m $\sigma = 0.0082 \times 10^{-6}$m	7.20×10^{6}

optical density ranged from 0.070 to 0.034. 'Harbor' was optically more dense by approximately one order of magnitude, and optical density varied inversely with wavelength. At 470 nm optical density was 0.622 and at 640 nm, 0.484.

B. Apparatus

The principal item of apparatus, common to all experiments performed as part of the present series, was a 70-gallon watertight test tank with a full-facemask mounted at one end. A drywell within the tank could be positioned along the long axis of the tank at distances from the faceplate between 5 and 64 centimeters (2 and 25 inches). Details and photographs of this basic apparatus are contained in prior reports.

For the present experiment, an optical system was placed in the drywell in direct line of sight of the facemask. The system was composed of three components:

- A 3-digit self-luminous fiber optic display whose readout could be controlled by the experimenter in the range 000-999. In front of the display was a pair of parallel slots for holding a single color filter.
- Two circular 4 log unit neutral density wedges positioned in front of the display-with-filter-holder unit. The rotation of one wedge was motorized and could be initiated by the experimenter and stopped by the observer. The second wedge served to make major adjustments in display output.

- An image reduction lens positioned in front of the wedge which could be placed either in or out of the line of sight to the display.

External to the drywell was a control unit by which the experimenter could specify the 3-digit readout, initiate the rotation of the circular wedge and read the position of the wedge. The observer held a single control, a switch which stopped the rotation of the wedge.

The rotation of one neutral density wedge was driven by an electric motor at a rate of one complete (360°) revolution per minute. Starting at the most dense section of the wedge, rotation gradually reduced the density over a 4.0 log unit range to the clear section of the wedge. Rotation of the wedge was sensed by a potentiometer on the shaft and one full rotation was divided into 830 units, i.e., when the wedge was darkest in front of the display the readout was 000, when entirely clear, 830.

Seven 'color' filters were used in the experiment and each filter reduced the total luminance of the basic fiber optic display to different extents. Therefore, the value, in luminance, of display output at a given wedge position varied from filter to filter. The wedge x filter calibration procedure is described in Section E, Display Variations. The result of the procedure, however, was seven computer print-out tables of luminance values vs wedge position between 000 and 830; a separate table for each color filter.

The components of the optical apparatus are shown in Figure 1. To the left of the figure is the unit placed in the drywell; to the right is the experimenter's control box and the observer's switch.

C. Observer Characteristics and Experimental Tasks

Ten enlisted men of Sea Air Land Team Two (SEAL TWO), and an officer of Special Warfare Group Two staff participated in the experiment as observers. Their average age was 30.8 years (range was 24-36 years). They had normal color vision, 20/20 near acuity, and an average accommodation near-point of 14.5 cm (range was 10-19 cm). Their names are listed alphabetically in Appendix B.

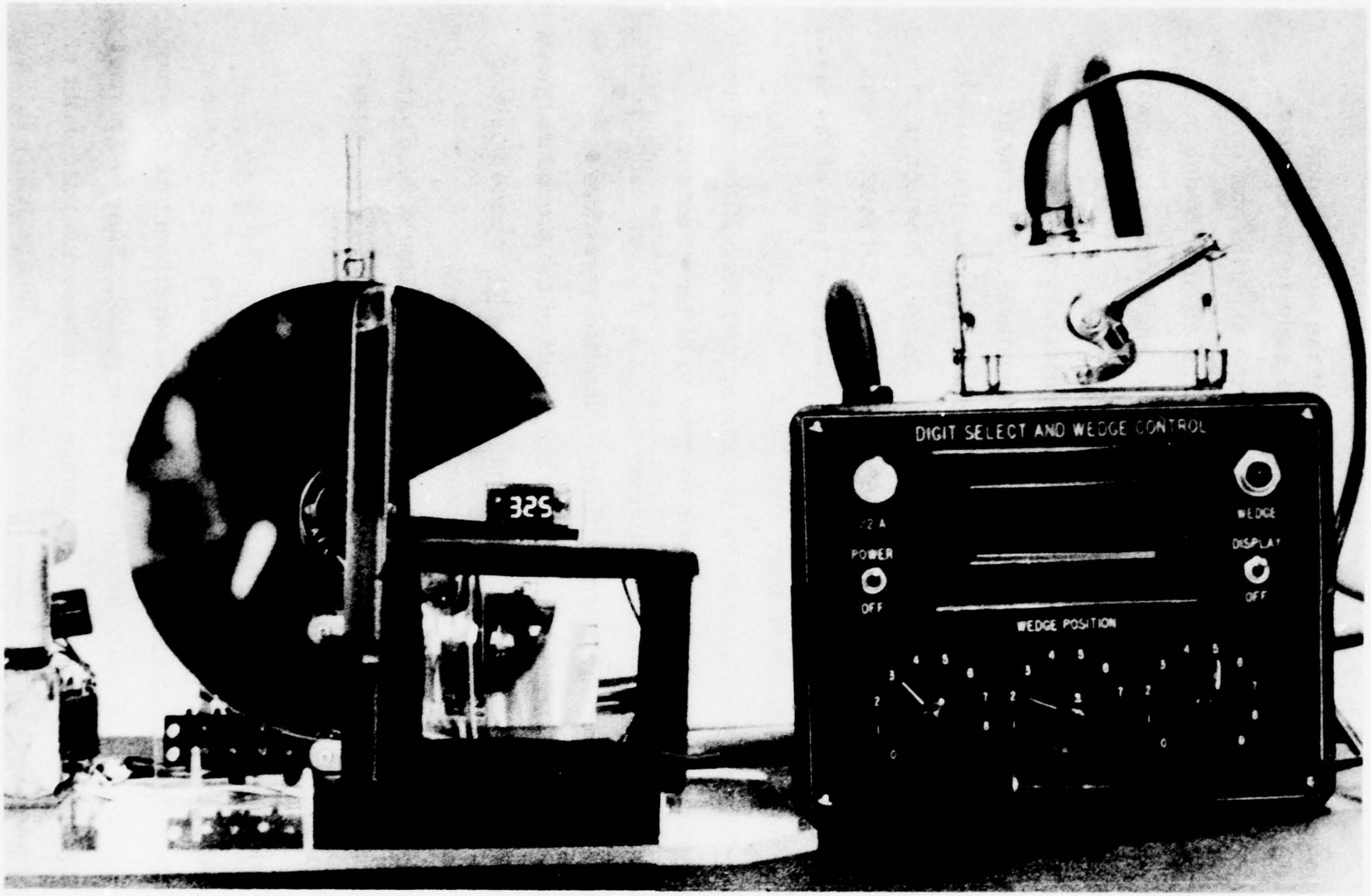

Figure 1. Apparatus

The observer was dark-adapted for twenty minutes, run through a trial, then re-dark-adapted for five minutes prior to the next trial. Each trial consisted of a 3-digit display at one of seven wavelengths (colors) at one of two sizes, and viewed through either 'Ocean' or 'Harbor' turbidity. Initially the display was dark beyond recognition but gradually increased in luminance as the wedge rotated. During the progress of the trial,the observer made a three-step series of judgments about the legibility of the display, stopping the wedge three times: first when the display became just readable, second, when clearly readable, and third, at the limit of acceptable luminance. These legibility levels were labeled 'Minimum', 'Clear' and 'Limit'.

At each of these three legibility levels (wedge rotation stops), the observer was asked to describe the color appearance of the display using one or a combination of two color names from a restricted set.

D. Dependent Variables

1. Legibility Criteria

One purpose of the experiment was to determine a range of luminance values for self-luminous display legibility which would more closely approximate engineering application than do traditional approaches to legibility based on sensory thresholds. The characteristics of the fiber optic display provided fairly well-defined bases for defining three levels of legibility. The digits were generated by full or partial patterns of 21 fiber ends which gave the appearance of lighted dots. All 21 formed the digit '8' and subsets of the 21 dots formed the remaining digits. Essentially the digits were created as in a seven-segment filament display where each line segment was replaced by three dots.

The appearance of the digits as formed by a pattern of dots changed with luminance. At low levels of luminance the dots were not distinct and the digit appeared as if formed by slightly wavy lines. As luminance increased, the

dots became distinct and the digit was seen clearly as composed of a dot pattern rather than an irregular line pattern. As luminance continued to increase, the dots appeared to enlarge and merge, creating the appearance of a digit formed by overly bright, fuzzy lines. These shifts in the appearance of the display were used to define three levels of legibility as follows:

- 'Minimum': The three digits of the display are legible as a pattern of slightly irregular lines.
- 'Clear': The three digits are legible as a sharply defined pattern of distinct dots.
- 'Limit': The three digits are legible as a pattern of bright line segments, the dots are no longer seen as distinct and separate.

2. Color Appearance

A second objective of the experiment was to assess the relative stability of the color appearance of different wavelengths over a range of viewing conditions. Of particular interest was the potential of the two turbidity conditions to effect changes in color appearance of a given display wavelength. The color appearance of a stimulus was estimated by the color-naming technique described by Boynton, Schafer and Neun, 1964. This color-naming procedure restricted observer's responses to one or a combination of two color names from a set of five: Blue, Green, Yellow, Red and White. Observer had two options. He could describe the display by one color name only, or he could call the display by two color names, the first name as the dominant color and the second name in the combination as a secondary color. For example, the observer could describe a 473 nm display as 'blue' or as a variety of combinations such as 'blue/white', 'blue/red' or 'blue/green'. Scoring of the response was to award a total of three points per trial to the colors named. All three to the color name if it was the only name given; otherwise two points to the first and one point to the second member of a combination.

Color appearance of the display was described and scored in this way at each legibility criterion on each trial.

E. Display Variations

The basic light source was a three-digit, self-luminous fiber optic display manufactured by Industrial Electronic Engineers, Inc., of Van Nuys, California. The display is commercially designated as IEE-Helios, High Intensity Fiberoptic Display. Average luminance of a fiber end or 'dot' was 1433 ft-L (4909.458 cd/m^2) as measured in air using a photopically calibrated Spectra-Pritchard Photometer Model 1980, an MS-80 lens and a 6' spot.

Display variations were introduced by optically modifying the constant output of this light source. Size differences were produced by the insertion of a reduction lens into the line of sight to the display. Wavelength differences were controlled by the insertion of interference filters into the eye-to-display path.

1. Display Size

The digits of the basic display measured 6.0 x 3.0 mm without the lens and were reduced to 3.0 x 1.5 mm with the lens. In the 'Ocean' simulation, display size was varied at two levels: 41' and 23' visual angle by positioning the drywell at 25 cm and 45 cm from the facemask and using the reduction lens. This procedure confounded the effects of display size and viewing distance in order to obtain a significantly smaller visual angle.

In the 'Harbor' turbidity, display size was varied at 41' and 82' visual angle by using the two display sizes at one viewing distance, 25 cm. This enabled effects of 'Harbor' and 'Ocean' turbidity environments to be compared under a common condition of display size and viewing distance, 41' visual angle.

2. Display Wavelength

Six narrow-band wavelengths and a white display were produced by appropriate filters. The narrow-band, glass interference filters were obtained from Bausch and Lomb, Inc., of Rochester, New York. Their transmission characteristics are presented in Table 2. The white display condition was produced by inserting in front of the basic display a blue acetate filter: Rosocolux No. 62, Booster Blue.

Table 2. Transmission Characteristics of the Interference Filters

Peak Wavelength	Percent Transmission at Peak Wavelength	Half-Band Pass (Bandwidth at 50% Transmission)
473 nm	43%	468-478 nm
503 nm	43%	498-508 nm
552 nm	35%	548-556 nm
579 nm	38%	575-583 nm
608 nm	38%	603-613 nm
640 nm	44%	635-645 nm

The narrow-band filters reduced the total energy of the basic display by varying amounts and established the upper limit of luminance that could be experimentally produced at each wavelength. The Roscolux acetate filter had much less of an effect; and in order to adjust its upper limit to the others, the second neutral density wedge was used. Resulting limits on display luminance per filter are presented in Table 3.

Table 3. Luminance Limit for Each 'Color' Filter

Filter	Luminance Limit (ft-L)
473 nm	3.45
503 nm	14.52
552 nm	49.30
579 nm	55.20
608 nm	65.70
640 nm	49.80
White	66.40

In order to translate wedge positions into display luminance, the wedge was calibrated for each color filter. Rather than measure all fiber ends and calculate their average luminance, a single fiber, whose luminance approximated the average, was selected to represent the display. One fiber of the left digit had a luminance of 1468 ft-L and was judged to adequately represent the mean of the several fiber ends, 1433 ft-L.

With each color filter in place, luminance measurements were taken at 50 wedge positions between 001 and 829. Then a computer program was written which interpolated all intermediate values. Computer printouts of ft-L x wedge position were generated by the program for each filter at wedge intervals of 001.

F. Experimental Design and Procedure

The luminance data were collected and analyzed within the framework of a 2 x 2 x 7 factorial design with repeated measurements. Seven color

stimuli were presented at two display sizes in two turbidity environments. All fourteen stimulus combinations were run for the 'Ocean' condition and then in the 'Harbor'. Within turbidity environments, display size order effects were counterbalanced between observers, and presentation order of the seven color stimuli were individually randomized. In order to control whole-display output on each trial, the 3-digit display was a random combination of those digits composed of a 15-dot pattern (2, 3, 5, 6 and 9). An outline of the experimental design is shown in Table 4.

Table 4. Experimental Design Outline

Color Filter (nm) \ Display Size	'Ocean' Turbidity		'Harbor' Turbidity	
	3 mm at 45 cm or 23'	3 mm at 25 cm or 41'	3 mm at 25 cm or 41'	6 mm at 25 cm or 82'
473				
503				
552				
579				
608				
640				
White				

Data were collected from eleven observers during the period 27 February through 3 March 1978 using the 'Ocean' turbidity simulation as a viewing environment; during 6-14 March 1978 the trials were repeated with the 'Harbor' turbidity condition. Observers were screened for normal color vision, 20/20 near acuity and accommodation near-point of less than 25 cm. They were briefed about the purpose of the experiment and the intended application of results to the design of submersible consoles. The three legibility judgments the observer was required to make were explained. The five color names and the restrictions on how to use the color names in describing the color appearance of each display were described. Practice runs in a high ambient light environment were made to familiarize the observer with the apparatus and use of the wedge-stopping switch. The test room was made dark and the observer was dark-adapted 20 minutes. Data trials were run using the following procedure:

- Experimenter set up the display size/color filter combination and indicated, 'Ready'.
- Observer put his face into the full facemask, and experimenter initiated rotation of the neutral density wedge.
- Observer stopped wedge at 'Minimum' legibility criterion, and experimenter recorded wedge position.
- Observer described color appearance of the display as one, or an ordered combination of two color names from the restricted set; experimenter recorded the color name(s) given.
- Experimenter continued the rotation of the wedge and observer stopped the wedge at the 'Clear' legibility criterion and described the color appearance; experimenter recording wedge position and color name(s) associated with 'Clear' legibility.
- Continuation of the procedure through 'Limit' legibility criterion. End of trial. Experimenter reset the wedge to its start position (fully dark) and observer re-dark-adapted for 5 minutes.

Total time required for a single trial, as recorded by stop watch, was on the order of 2.5 to 3.0 minutes. The five-minute inter-trial, dark-adaptation interval was chosen based on the work of Luria and Kinney, 1961.

G. Data Analyses and Statistical Tests

The analysis of the luminance data was straightforward. The analysis of variance procedure for a two-factor, repeated measures design as discussed by Winer (1962) was used as a model. The analyses were made using the data of ten of the eleven observers. The eleventh observer's pattern of responses was irregular and not consistent with the other ten. A risk criterion of $p < .01$ was used to evaluate the results of the analyses since the repeated measures design is particularly efficient in detecting significant differences. Also the omega squared (ω^2) statistic (Hays, 1973) was computed for each significant effect as an estimate of the total variance in luminance settings accounted for by the effect.

The analysis of the color-name data was complicated by the large number of potential comparisons and by the lack of a statistical test model completely compatible with the characteristics of the data. The number of comparisons to be made was reduced by the imposition of constraints based on potential applications. Operationally, the display was assumed to be used primarily at the luminance associated with 'Clear' legibility and so 'Minimum' and 'Limit' luminances were ignored except when Luminance was tested as a main effect. The two turbidity conditions could only be compared at the 41' visual angle display size and so the 23' and 82' sizes were ignored except when Display Size was being tested as a main effect.

These restrictions resulted in three sub-sets of main effect comparisons for water turbidity, display size and display luminance as follows:

- The wavelengths were compared in 'Harbor' vs 'Ocean' turbidity conditions at one display size (41') and at one display luminance, ('Clear').
- The wavelengths were compared at Large vs Small display size separately within the turbidity conditions and at 'Clear' legibility luminance.
- The wavelengths were compared at three levels of display luminance in the 'Ocean', and at two levels of luminance in the 'Harbor' at a display size of 41' visual angle.

The lack of an appropriate statistical test model for the color-name responses was resolved by compromising the Chi-Square test. Ten observers distributed three points to one or two color-name categories in response to a light stimulus under the two or three sets of conditions to be compared (e.g., 'Ocean' vs 'Harbor'; 'Minimum' vs 'Clear' vs 'Limit'). These points were aggregated over observers so that the score distribution characterizing the appearance of a given stimulus was based on thirty points which were treated as frequencies in the Chi-Square test. Significance of a given main effect on the color appearance of a light stimulus was tested by comparing the two or three aggregated distributions of frequencies over the color-name categories. This procedure had the effect of artificially enlarging the number of observers from 10 to 30. Applications of the Chi-Square tests were made as a modest improvement over inspection as a means to detect differences in color names describing a light stimulus under different conditions of size, luminance and viewing media.

III. RESULTS

A. Luminance Requirements for Display Legibility in Dark Underwater Viewing Environments*

1. Effects of Turbidity Variations on Luminance Requirements

The effects of 'Ocean' vs 'Harbor' turbidity conditions were assessed for one display size: 41 minutes of visual angle, i.e., a 3 mm display size at 25 cm viewing distance. Analysis of variance summary tables (Table 5) show turbidity differences to be significant determinants of display luminance requirements at both 'Minimum' and 'Clear' levels of legibility. The two viewing environments could not be compared at 'Limit' legibility since none of the seven stimuli could be made sufficiently intense to achieve the limit criterion in 'Harbor' turbidity. Turbidity differences accounted for 50% and 66% of the total variance in luminance settings at 'Minimum' and 'Clear' legibility levels. Display color was not a significant contributor to luminance requirements.

Table 5. ANOVA Summary Tables for Factors Affecting Display Luminance Requirements in 'Ocean' vs 'Harbor' Viewing Environments

1. At Minimum Legibility: Six colors, two sizes

Source	df (Source, Error)	MS_s/MS_e	F	p	$\hat{\omega}^2$
Turbidity (T)	1, 9	1775.8510/39.1908	45.31	<.01	.50
Color (C)	5. 45	11.7904/8.9444	1.32	N.S.	
T x C	5, 45	11.9791/8.9561	1.34	N.S.	

2. At Clear Legibility: Five colors, two sizes

Source	df (Source, Error)	MS_s/MS_e	F	p	$\hat{\omega}^2$
Turbidity (T)	1, 9	28323.5200/367.9460	76.98	<.01	.66
Color (C)	4, 36	243.8179/72.0793	3.38	N.S.	
T x C	4, 36	239.8989/71.6271	3.35	N.S.	

*Raw data are tabled in Appendix C.

Table 6 presents the mean display luminances required for legibility at 'Minimum' and 'Clear' criterion levels for the two turbidity conditions. In the 'Ocean' viewing environment, average luminance requirements at 'Minimum' and 'Clear' legibility were one order of magnitude apart: 0.07 ft-L for 'Minimum' legibility and 0.70 ft-L for 'Clear' legibility. In 'Harbor' turbidity, mean luminance requirements were 7.60 ft-L for 'Minimum' legibility and 34.30 ft-L for 'Clear'; a difference of approximately 0.5 log unit luminance.

Table 6. Display Luminance (ft-L) Required for Legibility in 'Ocean' and 'Harbor' Turbidity

Turbidity Condition	Legibility Criterion	
	'Minimum'	'Clear'
'Ocean'	0.07	0.70
'Harbor'	7.60	34.30

2. Effects of Display Size Variations on Luminance Requirements

a. In 'Ocean' Turbidity. In the relatively clear water defining 'Ocean' turbidity, the effects of display size and color could be assessed at three levels of legibility. Display size was varied at two levels: 23' and 41' visual angle. Display color could be tested at seven wavelengths for the 'Minimum' and 'Clear' legibility levels but at only four wavelengths in the 'Limit' conditions. Table 7 presents ANOVA summaries for each legibility criterion. Results show display size as a significant determinant of luminance requirements at 'Minimum' and 'Clear' legibility levels, accounting for 28% and 18% of the total response variance. Luminance requirements at the limit of legibility were not significantly different for the two display sizes. Display color was not a significant factor in accounting for luminance requirements.

Table 7. ANOVA Summary Tables for Factors Affecting Display Luminance Requirements in 'Ocean' Turbidity

1. At Minimum Legibility: Seven colors, two sizes

Source	df (Source, Error)	MS_s/MS_e	F	p	ω^2
Color (C)	6, 54	.0035/.0037	<1	N.S.	-
Size (S)	1, 9	.2561/.0070	36.22	<.01	.28
C x S	6, 54	.0010/.0031	<1	N.S.	-

2. At Clear Legibility: Seven colors, two sizes

Source	df (Source, Error)	MS_s/MS_e	F	p	ω^2
Color (C)	6, 54	1.5384/.60711	2.53	N.S.	-
Size (S)	1, 9	17.7074/.6143	28.82	<.01	.18
C x S	6, 54	.5673/.3936	1.44	N.S.	

3. At Limit Legibility: Four colors, two sizes

Source	df (Source, Error)	MS_s/MS_e	F	p	ω^2
Color (C)	3, 27	1372.0690/440.6609	3.11	N.S.	-
Size (S)	1, 9	439.3030/535.7012	<1	N.S.	-
C x S	3, 27	321.8872/352.7510	<1	N.S.	-

Table 8 presents the mean luminance required for the two display sizes at three legibility levels. The larger of the two display sizes required slightly less luminance to be seen at both 'Minimum' and 'Clear' legibility. The size-related difference in luminance at 'Limit' legibility was not statistically significant, but provided an estimate of the upper limit of luminance needed in a display for the 'Ocean' viewing environment: approximately 40 ft-L.

Table 8. Display Luminance (ft-L) Required for Legibility of Small- and Large-Sized Displays in 'Ocean' Turbidity

<table>
<tr><th rowspan="2">Display Size</th><th colspan="3">Legibility Criterion</th></tr>
<tr><th>'Minimum'</th><th>'Clear'</th><th>'Limit'</th></tr>
<tr><td>23' Visual Angle</td><td>0.16</td><td>1.40</td><td rowspan="2">40.0</td></tr>
<tr><td>41' Visual Angle</td><td>0.07</td><td>0.70</td></tr>
</table>

b. In 'Harbor' Turbidity. In order to expand the range of the size variable examined in the experiment, display size in 'Harbor' turbidity was varied at two levels: 41' and 82' visual angle. At a viewing distance of 25 cm, these visual angles correspond to display sizes (height dimension) of 3 mm and 6 mm. At 'Minimum' legibility, the 473 nm wavelength was excluded, and at 'Clear' legibility both 473 nm and 503 nm wavelengths were excluded from the analyses for lack of adequate brightness. Table 9 presents the ANOVA summary tables for the two legibility criterion levels. At 'Minimum' legibility, display size was a significant determinant of required luminance and accounted for 18% of the total variance. At 'Clear' legibility, display size was again a significant factor affecting luminance requirements and

accounted for 53% of the total response variance. Color differences had no significant effect on luminance requirements.

Table 9. ANOVA Summary Tables for Factors Affecting Display Luminance Requirements in 'Harbor' Turbidity

1. At Minimum Legibility: Six colors, two sizes

Source	df (Source, Error)	MS_s/MS_e	F	p	$\hat{\omega}^2$
Color (C)	5, 45	16.4789/10.3579	1.59	N.S.	-
Size (S)	1, 9	880.3127/38.6099	22.80	<.01	.18
C x S	5, 45	8.8357/8.6289	1.02	N.S.	-

2. At Clear Legibility: Five colors, two sizes

Source	df (Source, Error)	MS_s/MS_e	F	p	$\hat{\omega}^2$
Color (C)	4, 36	265.8323/84.754	3.14	N.S.	-
Size (S)	1, 9	17296.98/260.4883	66.40	<.01	.53
C x S	4, 36	221.3789/70.638	3.13	N.S.	-

Table 10 presents the mean luminances required for legibility at two criterion levels as a function of differences in display size.

Table 10. Display Luminance (ft-L) Required for Legibility of Small- and Large-Sized Displays in 'Harbor' Turbidity

Display Size	Legibility Criterion	
	'Minimum'	'Clear'
41' Visual Angle	7.6	34.3
82' Visual Angle	2.3	8.0

B. Color Appearance of Self-Luminous Displays in Dark Underwater Viewing Environments*

1. Baseline Color Appearance

As a standard for comparison, a baseline color appearance for each of the seven stimuli was derived from the color-name responses given under the optimum combination of display variables and viewing environments: a large-sized (41'), clearly-legible (0.70 ft-L) display viewed through the relatively clear water of the 'Ocean' turbidity condition. Table 11 is the proportion of thirty scores awarded each color-name category in response to the white display and each of six narrow-band wavelength displays. The score distribution for each stimulus was examined to identify either the color name or combination of two color names which accounted for the majority of the scores, i.e., approximated 1.00. Then the raw data record was examined to verify that the pattern in the aggregated data also occured

*Raw data are tabled in Appendix D.

Table 11. Proportion of Color-Name Scores for Seven Stimuli At 'Clear' Legibility in 'Ocean' Turbidity

Display Wavelength	Color Names				
	Blue	Green	Yellow	Red	White
White	-	.03	.33	.03	.60
473 nm	.83	.07	-	-	.10
503 nm	.30	.67	.03	-	-
552 nm	.07	.63	.03	-	.27
579 nm	-	.07	.47	.03	.43
608 nm	-	-	.07	.77	.17
640 nm	-	-	.03	.93	.03

in the individual cases. Table 12 shows the frequency distribution of ten observers over 25 possible color-name responses for each of the seven stimuli. As an example, the score distribution for the white stimulus shows .60 'white' responses and .33 'yellow' responses. Was the display seen as 'white' or as 'white/yellow'? A review of the raw data records revealed only 1 of 10 observers who called the display 'white' only, and 5 of 10 observers who responded 'white/yellow'. The color appearance of 'white/yellow' both accounts for 94% of the total responses to the white stimulus in Table 11 and is consistent with the main pattern of color name combinations given by individual observers in Table 12. Results of this procedure carried through for each of the seven stimuli are presented in Table 13.

Table 12. Distribution of Ten Observers Over Color-Name Alternatives in Response to Seven Stimuli ('Ocean' Turbidity, 'Clear' Luminance, 41' Visual Angle)

Color-Name Alternatives	Stimulus Wavelengths						
	White	473 nm	503 nm	552 nm	579 nm	608 nm	640 nm
White	1			1	2		
Blue		7					
Green			3	2			
Yellow	1				3		
Red						4	8
W/B		1					
W/G	1			1			
W/Y	5				3		
W/R	1					1	1
B/G			3				
B/Y							
B/R							
B/W		1					
G/Y			1	1			
G/R							
G/W				3	1		
G/B		1	3	2			
Y/R					1	2	
Y/W	1						
Y/B							
Y/G							
R/W						3	
R/B							
R/G							
R/Y							1

Table 13. Color Appearance of Seven Stimuli At 'Clear' Legibility in 'Ocean' Turbidity

Display Wavelength	Color Appearance
White	White/Yellow
473 nm	Blue
503 nm	Green/Blue
552 nm	Green/White
579 nm	Yellow/White
608 nm	Red/White
640 nm	Red

2. Effects of Turbidity Variations on Color Appearance

Six of the stimuli could be compared in both 'Ocean' and 'Harbor' turbidities at 'Clear' legibility. The 473 nm stimulus was not sufficiently bright for the 'Clear' legibility criterion in 'Harbor' turbidity. Tests of significance of differences between the color-name score distributions revealed significant effects of turbidity on the color appearance of two stimuli: White and 608 nm. The white stimulus, seen primarily as 'white/yellow' in the 'Ocean' environment, was seen as mainly 'yellow' in the 'Harbor'. A Chi-Square test of 'white' vs 'yellow' scores in 'Harbor' vs 'Ocean' yielded $\chi^2 = 6.04$, df = 1 and $p < .02$. Of the ten observers, eight called the display either 'white' or primarily 'white' in 'Ocean', while six of ten called it 'yellow' or principally 'yellow' in the 'Harbor' viewing environment. This significant shift in aggregated color-name scores is illustrated in Figure 2.

The 608 nm stimulus, named by various combinations of 'red' and 'white' in the 'Ocean', was called by combinations of 'red' and 'yellow' in the 'Harbor' turbidity condition. The Chi-Square test yielded a value of 4.71, significant at

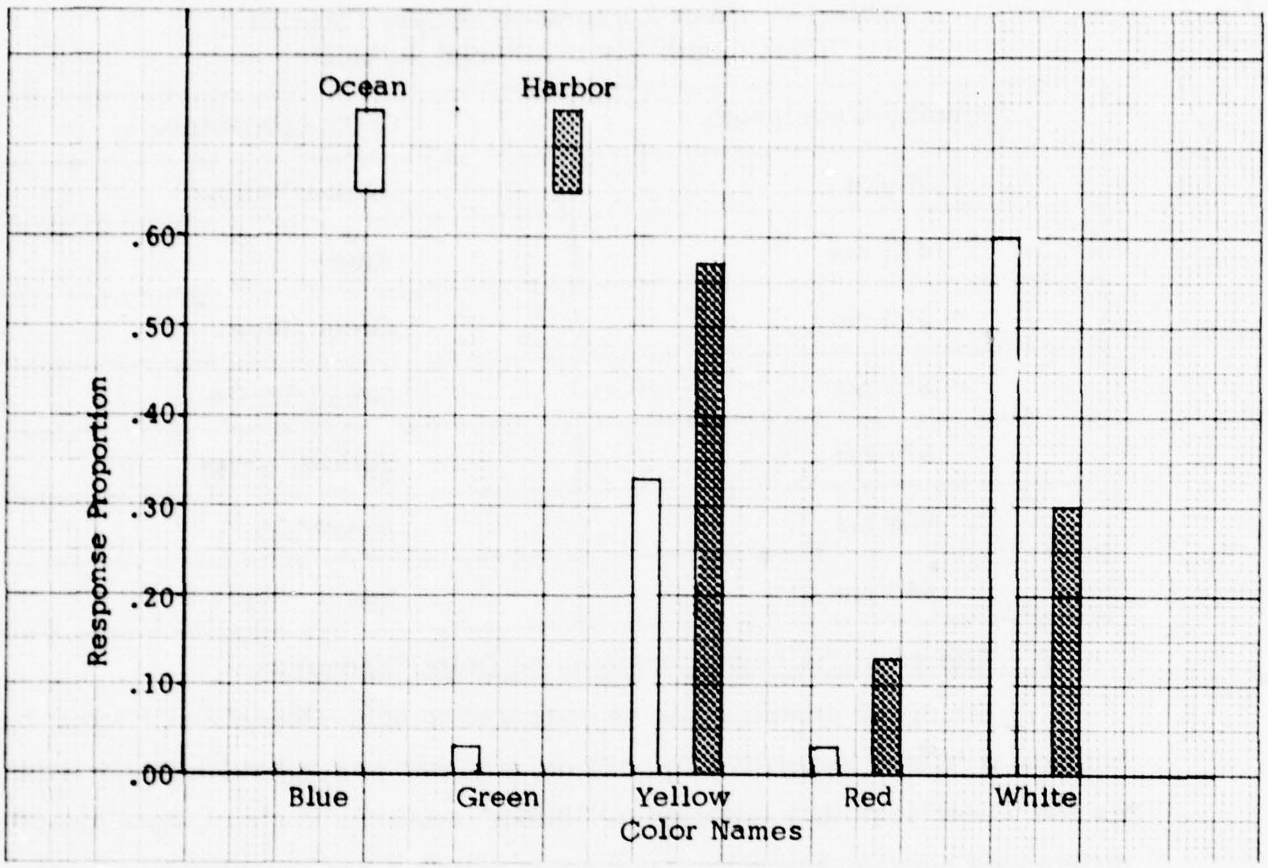

Figure 2. Distribution of Color-Name Scores in 'Ocean' vs 'Harbor' Turbidity: White Stimulus

$p < .05$ with one degree of freedom. In the 'Ocean', eight of ten observers used 'red' and 'white' to describe the 608 nm display; in the 'Harbor', eight of ten observers used 'red' and 'yellow'. The shift in color appearances from 'red/white' to 'red/yellow' is illustrated by the proportionate distribution of color-name scores in Figure 3.

None of the remaining stimuli was called by a different color name in the 'Harbor' environment according to the Chi-Square tests. The 640 nm stimulus was particularly stable in color appearance. The color-name 'red'

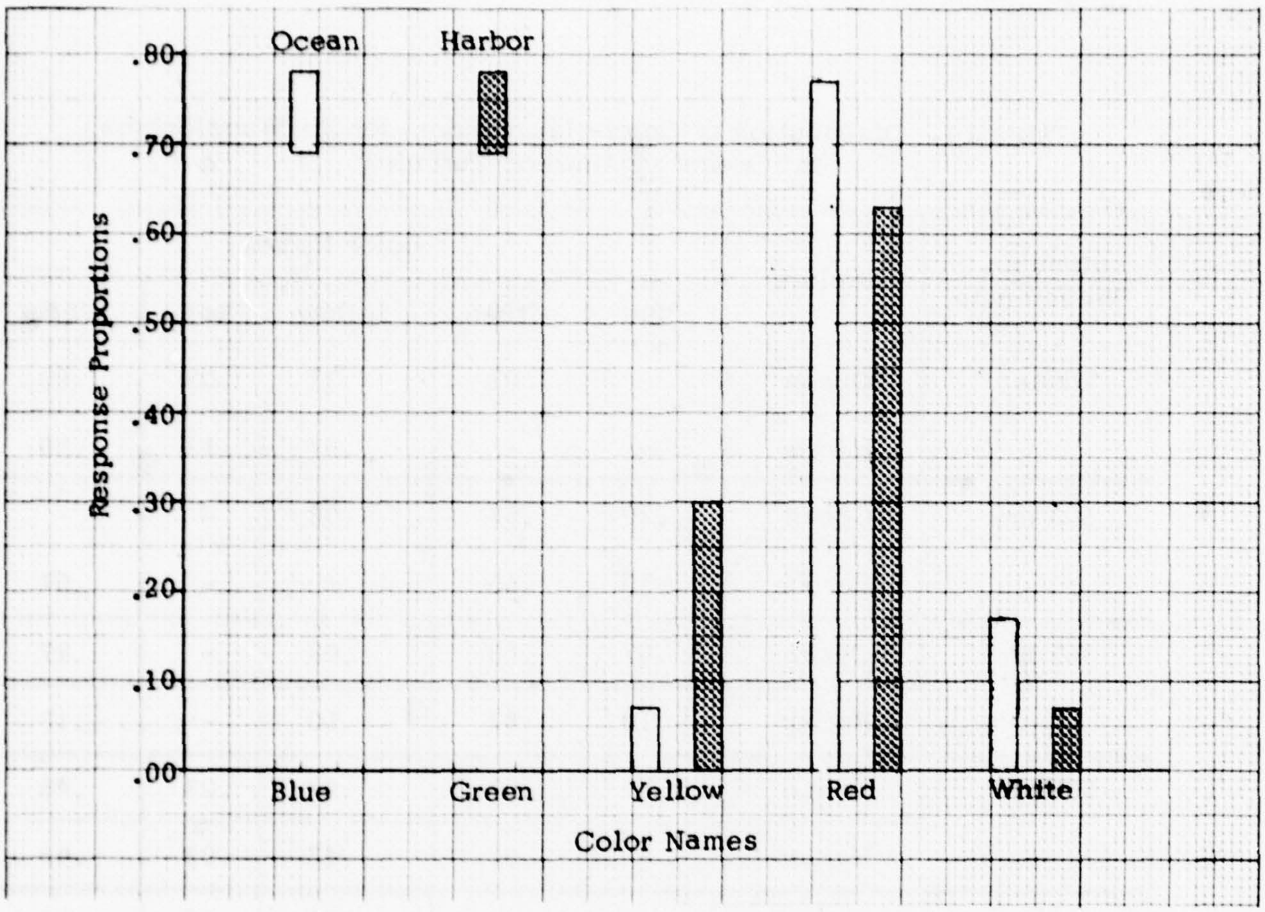

Figure 3. Distribution of Color-Name Scores in 'Ocean' <u>vs</u> 'Harbor' Turbidity: 608 nm Stimulus

accounted for 93% and 97% of the responses to the 640 nm stimulus in 'Ocean' and 'Harbor' turbidity; also 8 of 10 observers in the 'Ocean' and 9 of 10 in the 'Harbor' named the stimulus 'red'.

Table 14 presents the comparative color-name score distributions for six stimuli in both turbidities.

Table 14. Distribution of Color-Name Scores for Six Wavelengths in 'Ocean' *vs* 'Harbor' Turbidity

Stimulus Wavelength	Turbidity	Color Names				
		Blue	Green	Yellow	Red	White
White	Ocean	-	.03	.33	.03	.60
	Harbor	-	-	.57	.13	.30
503 nm	Ocean	.30	.67	.03	-	-
	Harbor	.30	.63	-	-	.07
552 nm	Ocean	.07	.63	.03	-	.27
	Harbor	.10	.67	.10	-	.13
579 nm	Ocean	-	.07	.47	.03	.43
	Harbor	-	.07	.47	.03	.43
608 nm	Ocean	-	-	.07	.77	.17
	Harbor	-	-	.30	.63	.07
640 nm	Ocean	-	-	.03	.93	.03
	Harbor	-	-	.03	.97	-

3. Effects of Display Size Variations on Color Appearance

a. In 'Ocean' Turbidity. Display size was varied at two levels: 23' and 41' visual angle based on the height dimension of the digits. The smaller size was achieved by viewing a 3 mm display at 45 cm viewing distance; the larger, at 25 cm. Size variations were assessed as determinants of color appearance at the 'Clear' legibility criterion: 1.40 ft-L for the 23' display, and 0.70 ft-L for 41' display size.

Size differences had a significant effect on color appearance of the 579 nm stimulus. The 'yellow' appearance of the smaller-sized display became desaturated at the larger size. When the Chi-Square test was applied to the 'yellow' vs 'white', small vs large contingency table of aggregate scores, $\chi^2 = 5.73$ and with 1 degree of freedom $p < .02$. The individual response patterns showed that 8 of 10 observers called the smaller-sized display 'yellow' or predominantly 'yellow'. At the larger display size, 5 of 10 observers called the display principally 'white', and 4 of 10 called it principally 'yellow'. The shift toward a desaturated 'yellow' appearance with increased display size is illustrated by Figure 4. None of the other size differences was significant according to the Chi-Square tests, and none was suggested by examination of the individual response patterns.

Distribution of color-name score proportions for all seven stimuli are shown in Table 15.

b. In 'Harbor' Turbidity. Display size in the 'Harbor' turbidity was varied at two levels: 41' and 82' visual angle. The variation was accomplished by using a 6 mm and a 3 mm display at a constant (25 cm) viewing distance. Color name comparisons as a function of display size were made at 'Clear' legibility, i.e., 34.3 ft-L at 41' and 8.0 ft-L at 82' visual angle. All but the 473 nm wavelength could be included in this analysis. Under these conditions, display size had no significant effect on color names. Table 16 presents the proportionate score distributions.

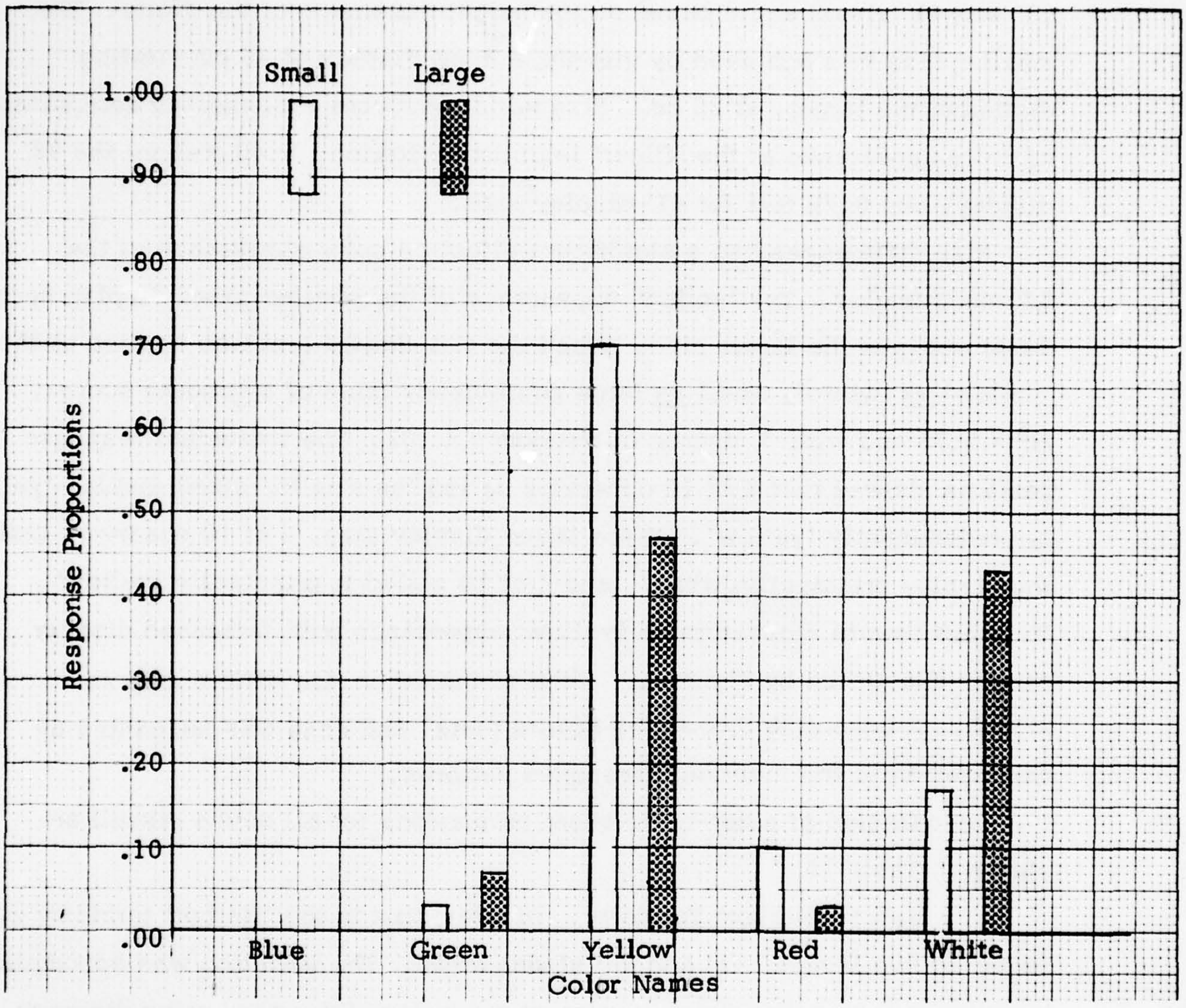

Figure 4. Distribution of Color Name Scores for Small- vs Large-Sized Digits at 'Clear' Legibility in 'Ocean' Turbidity: 579 nm Stimulus

Table 15. Distribution of Color-Name Scores for Small- and Large-Sized Digits At 'Clear' Legibility: 'Ocean' Turbidity

Stimulus Wavelength	Stimulus Size	Color Name				
		Blue	Green	Yellow	Red	White
White	Small (23')	-	.03	.43	.07	.47
	Large (41')	-	.03	.33	.03	.60
473 nm	Small (23')	.87	.07	-	-	.07
	Large (41')	.83	.07	-	-	.10
503 nm	Small (23')	.23	.73	.03	-	-
	Large (41')	.30	.67	.03	-	-
552 nm	Small (23')	.13	.63	.13	-	.10
	Large (41')	.07	.63	.03	-	.27
579 nm	Small (23')	-	.03	.70	.10	.17
	Large (41')	-	.07	.47	.03	.43
608 nm	Small (23')	-	-	.17	.77	.07
	Large (41')	-	-	.07	.77	.17
640 nm	Small (23')	-	-	.07	.90	.03
	Large (41')	-	-	.03	.93	.03

Table 16. Distribution of Color-Name Scores for Small- and Large-Sized Digits At 'Clear' Legibility: 'Harbor' Turbidity

Stimulus Wavelength	Stimulus Size	Color Name				
		Blue	Green	Yellow	Red	White
White	Small (41')	-	-	.57	.13	.30
	Large (82')	-	.03	.40	.40	.17
503 nm	Small (41')	.30	.63	-	-	.07
	Large (82')	.17	.67	.10	-	.13
552 nm	Small (41')	.10	.67	.10	-	.13
	Large (82')	.20	.50	.13	-	.17
579 nm	Small (41')	-	.07	.47	.03	.43
	Large (82')	-	.17	.50	-	.33
608 nm	Small (41')	-	-	.30	.63	.07
	Large (82')	-	-	.33	.63	.03
640 nm	Small (41')	-	-	.03	.97	-
	Large (82')	-	-	.03	.93	.03

4. Effects of Display Luminance Variations on Color Appearance

a. In 'Ocean' Turbidity. Color-name responses were obtained for all seven stimuli at 'Minimum', 'Clear' and 'Limit' levels of legibility. All stimuli were 41' visual angle in size; mean luminances of the display at these legibility criteria were 0.07, 0.70 and 40.0 ft-L. Two exceptions were made in order to include the 473 nm and 503 nm wavelengths at 'Limit' legibility. Neither of these stimuli could be made sufficiently bright to determine the upper boundary of legible luminance; however, color names were obtained at their maximum attainable value: 3.45 ft-L for 473 nm and 14.52 ft-L for 503 nm.

Variation in display luminance significantly affected the color appearance of all but the 503 nm wavelength. Three of the stimuli appeared more saturated as intensity increased: 473 nm, 579 nm and White. Two of the stimuli, 552 nm and 608 nm, evidenced color appearance shifts in accord with the Bezold-Brücke phenomenon; the 640 nm stimulus appeared to desaturate at the 40 ft-L level of display luminance. Figures 5 through 10 illustrate the color-name shifts of these stimuli.

The 473 nm display appeared progressively more 'blue' and less 'white' as intensity increased. The Chi-Square test of aggregated color-name scores was $\chi^2 = 10.58$, df = 2, $p < .01$. At the lowest luminance, the 473 nm display was called 'white' or 'white/blue' by 4 of 10 observers and 'blue' by 4 of 10. At 'Clear' and 'Limit' levels, the display was called 'blue' by 7 of 10 and 8 of 10 observers.

The 579 nm display was described as predominantly 'yellow' only at the luminance of 'Limit' legibility, i.e., 40 ft-L. At the two lower intensities, the display appeared highly desaturated and was named as predominantly 'white' by 5 of 10 observers at both 'Minimum' and 'Clear' legibility. At 'Limit' legibility, the 579 nm display was called predominantly 'yellow' by 8 of 10 observers. The Chi-Square test of aggregated color-name scores was $\chi^2 = 5.02$, df = 1, $p < .05$.

The White display appeared progressively more 'white' and less 'yellow' as luminance increased. The display was named as predominantly 'white' by 6 of 10, 8 of 10 and 10 of 10 observers as luminance increased from 'Minimum' to 'Clear' to 'Limit' legibility. The two color names by three luminances Chi-Square test was $\chi^2 = 8.04$, df = 2, $p < .02$.

The 552 nm stimulus shifted in color appearance from 'green/white' at 'Minimum' and 'Clear' legibility luminances to 'green/yellow' at 'Limit' luminance. Seven of the 10 observers called the 552 nm display 'green' or 'green/white' at the .07 and .70 ft-L levels; at the 'Limit' legibility value, 8 of 10 responded 'yellow' or 'green/yellow'. A 3 x 3 Chi-Square test of 'Minimum', 'Clear' and 'Limit' luminances against 'green', 'yellow' and 'white' color names yielded $\chi^2 = 18.51$, df = 4 and $p < .001$.

Color appearance of the 608 nm stimulus shifted from predominantly 'red' at .07 ft-L to 'red/white' at .70 ft-L to 'red/yellow' at 40.0 ft-L. Seven of 10 observers called the display 'red' at 'Minimum' legibility, 'red' and 'white' combinations accounted for 8 of 10 observer responses at 'Clear' legibility, 'red' and 'yellow' combinations were given by 6 of 10 observers at 'Limit' legibility. Agggregated color-name score distributions were tested in a 3 x 2 contingency table: three luminance levels against two color-name categories 'red' <u>vs</u> 'white' and 'yellow'. Frequencies were too few to test 'white' and 'yellow' names separately. Chi-Square was 5.71, df = 2, p .06

The number of non-red frequencies was too small for the Chi-Square test, but examination of the color-name responses suggests a shift in the color appearance of the 640 nm stimulus between 'Clear' and 'Limit' levels of display luminance. At the 'Clear' legibility luminance of 0.70 ft-L, 640 nm was called 'red' by 8 of 10 observers; at the 'Limit' legibility of 40.0 ft-L, 640 nm was called 'red' by only three observers; seven saw it as a desaturated red, and the modal response was 'red/white'.

Color-name score distributions for all seven stimuli are tabled in Table 17.

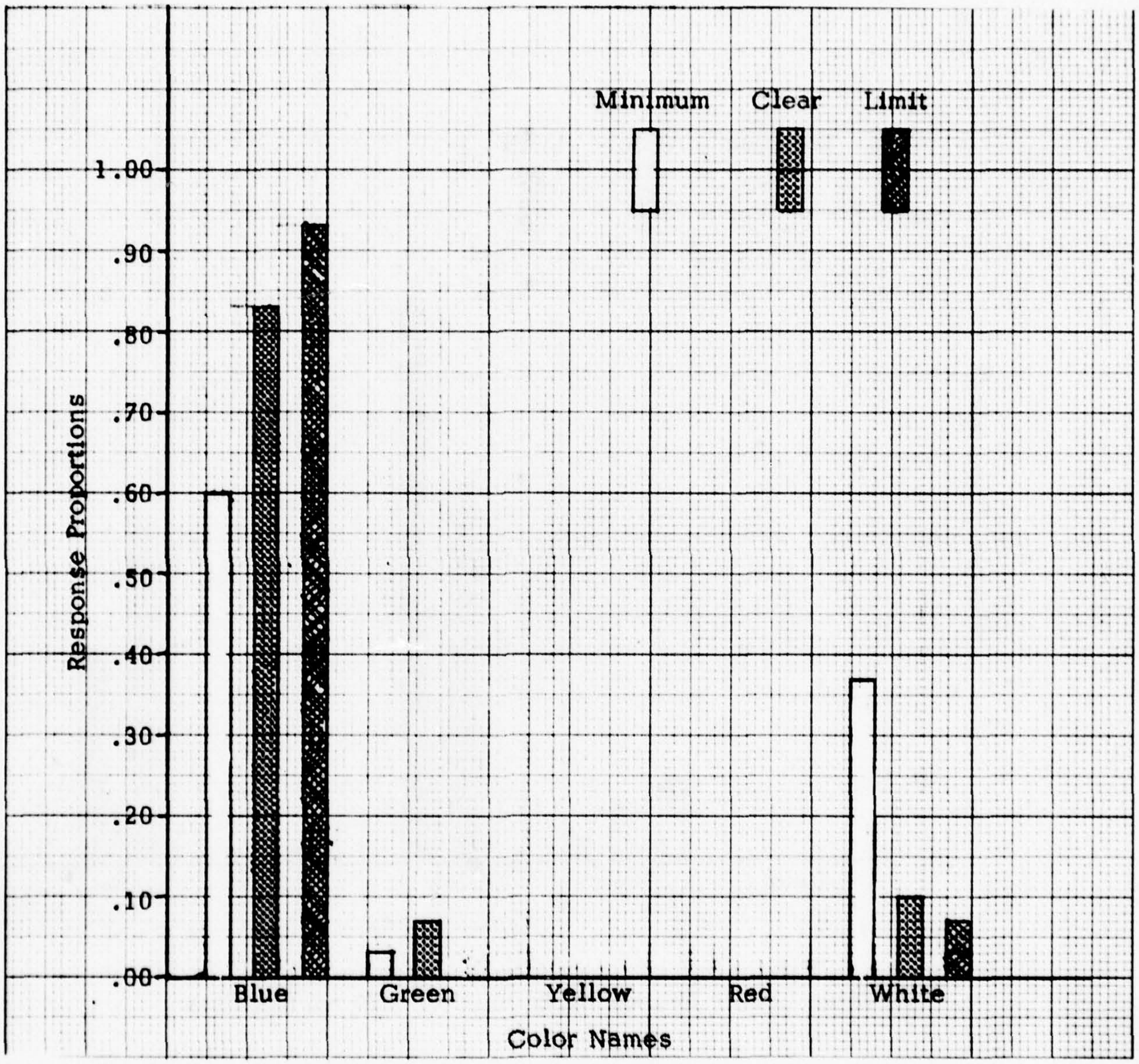

Figure 5. Distribution of Color-Name Scores in 'Ocean' Turbidity At Three Levels of Display Legibility: 473 nm Stimulus

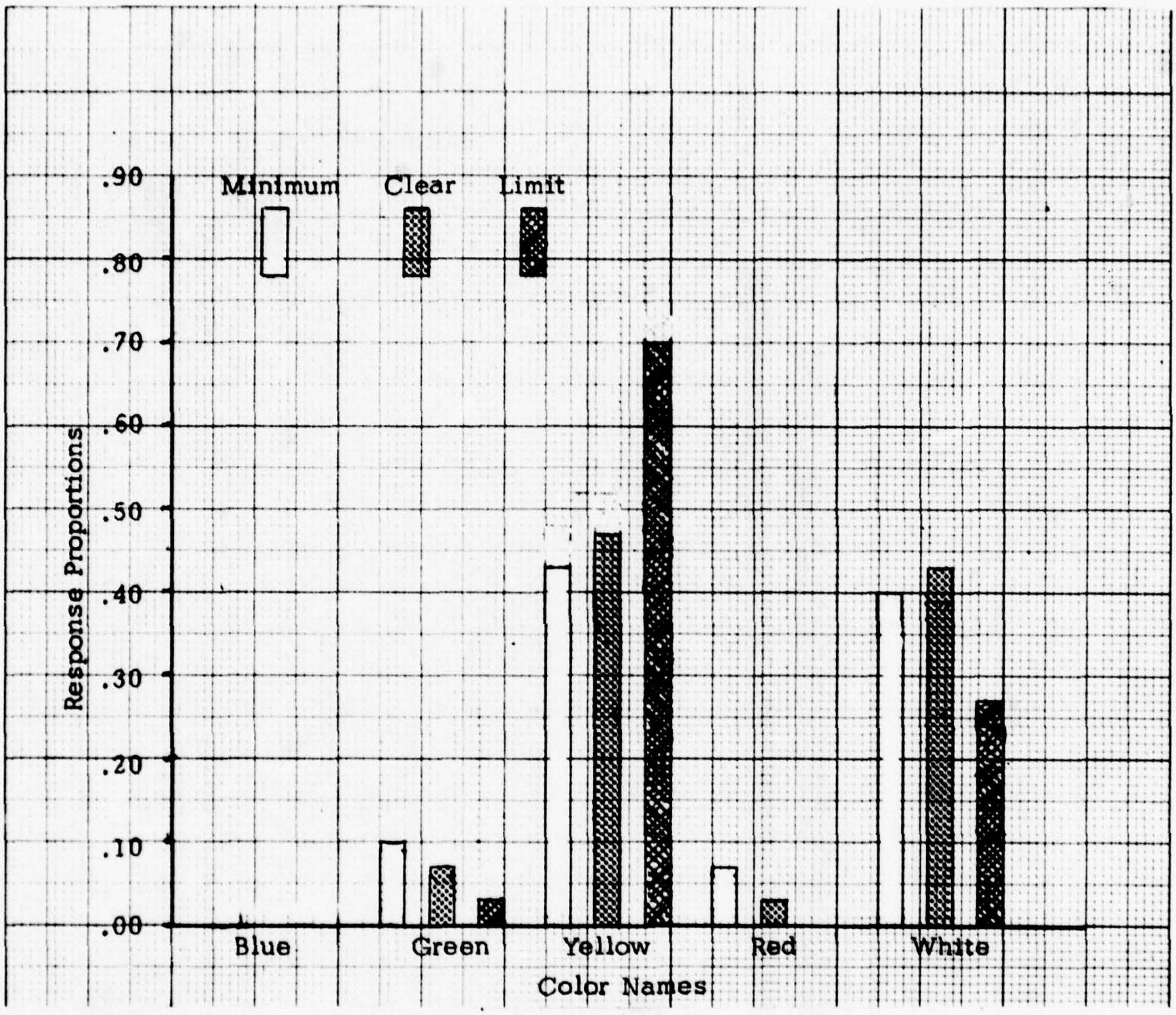

Figure 6. Distribution of Color-Name Scores in 'Ocean' Turbidity At Three Levels of Display Legibility: 579 nm Stimulus

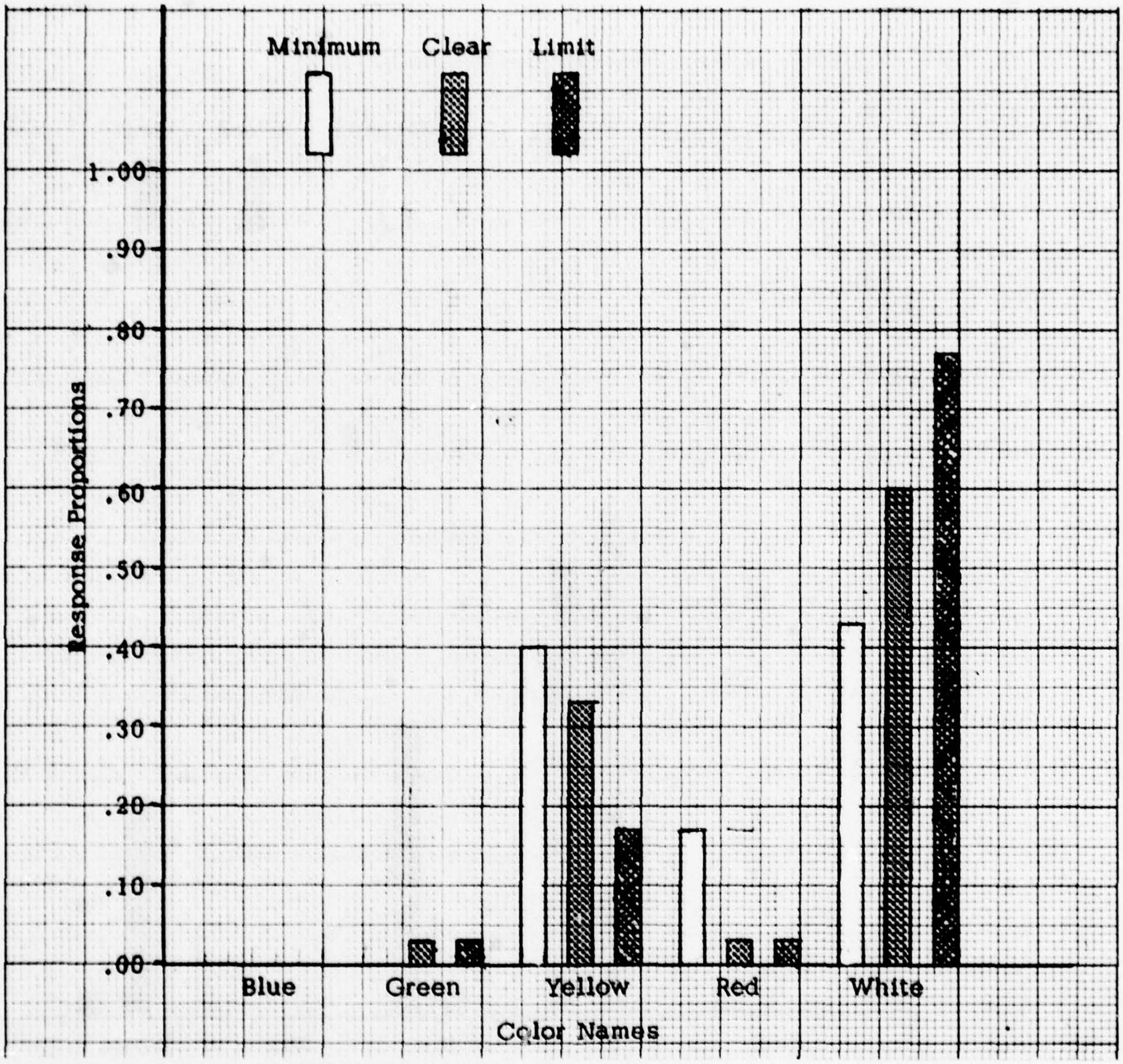

Figure 7. Distribution of Color-Name Scores in 'Ocean' Turbidity At Three Levels of Display Legibility: White Stimulus

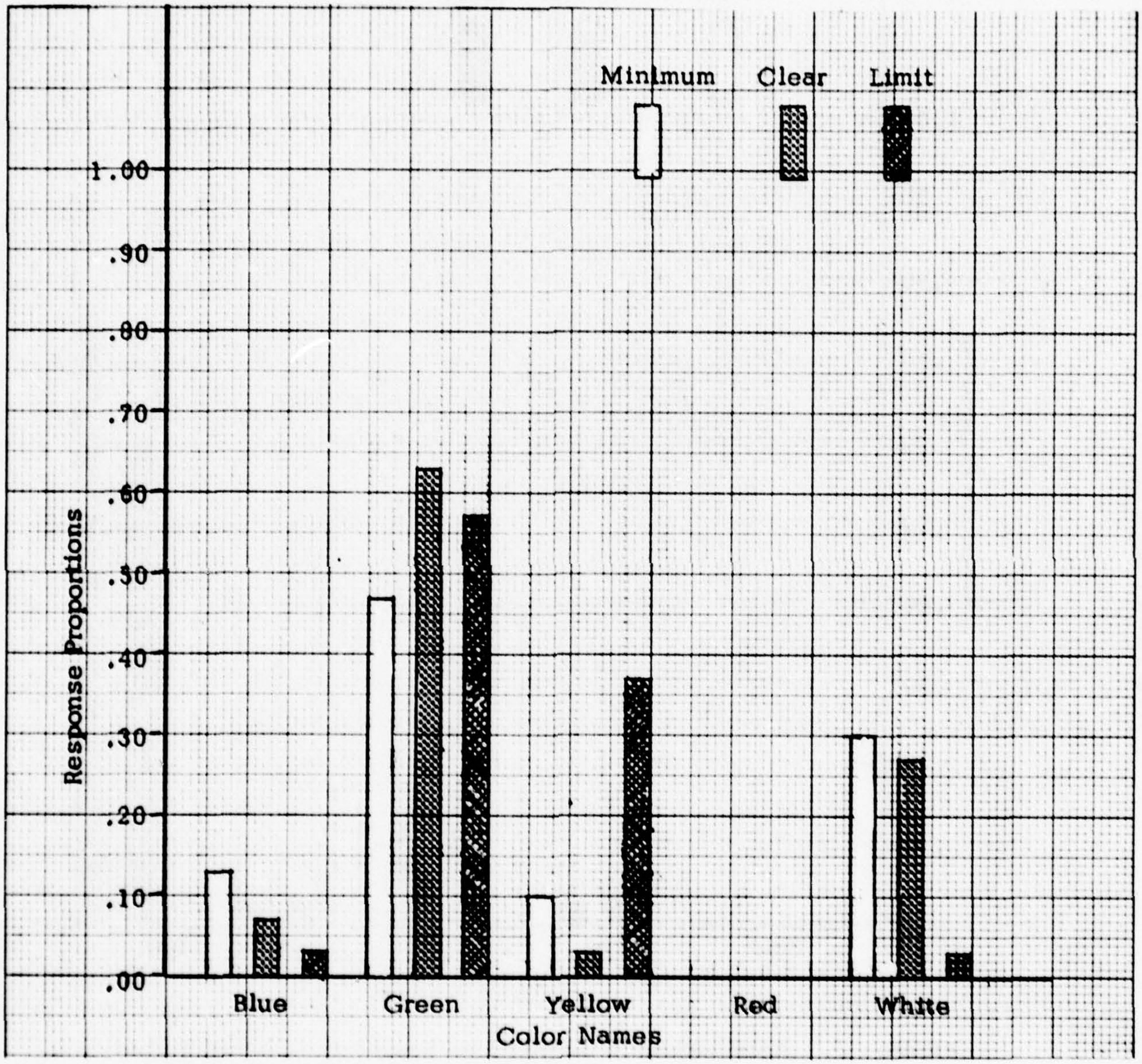

Figure 8. Distribution of Color-Name Scores in 'Ocean' Turbidity At Three Levels of Display Legibility: 552 nm Stimulus

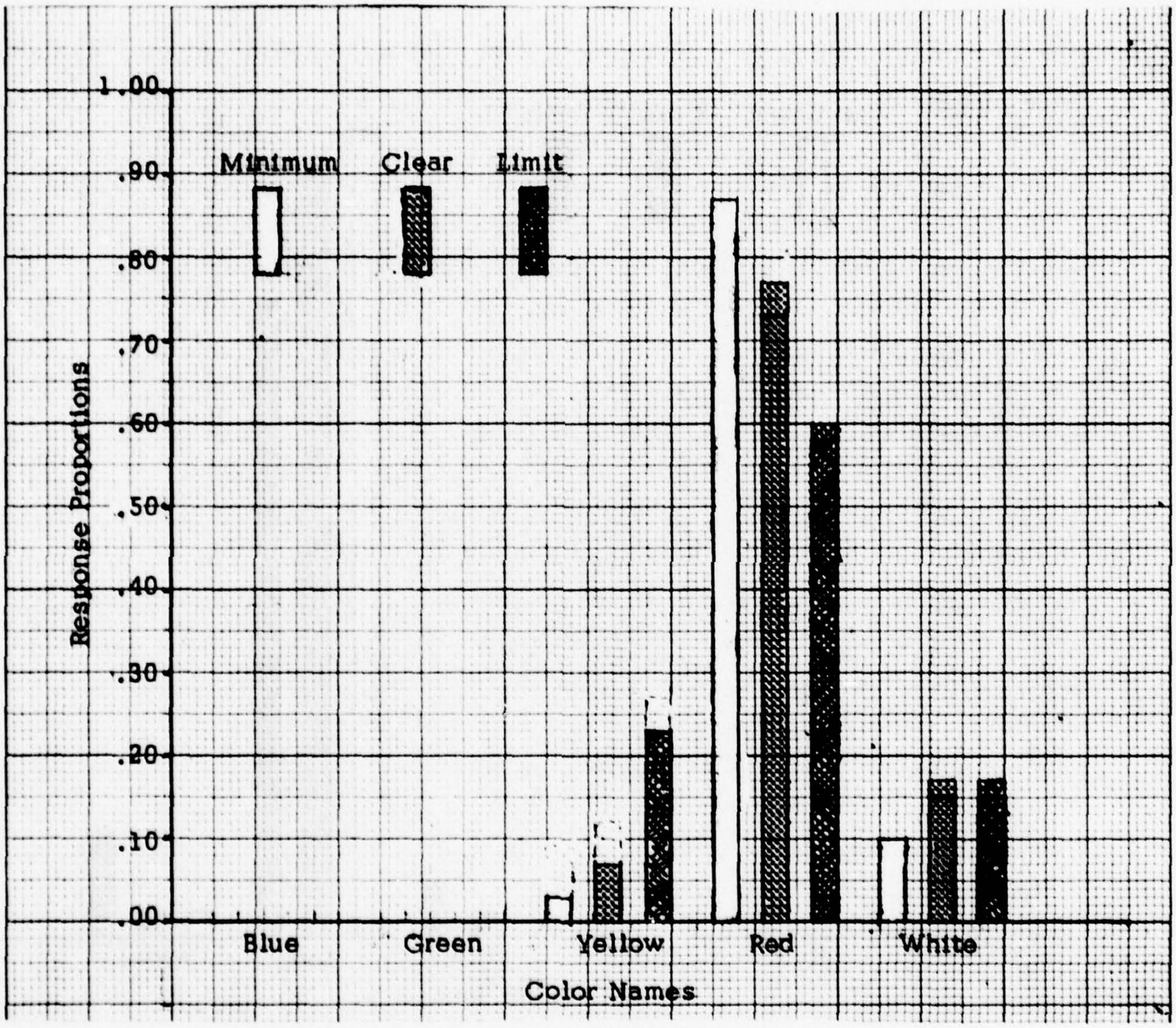

Figure 9. Distribution of Color-Name Scores in 'Ocean' Turbidity At Three Levels of Display Legibility: 608 nm Stimulus

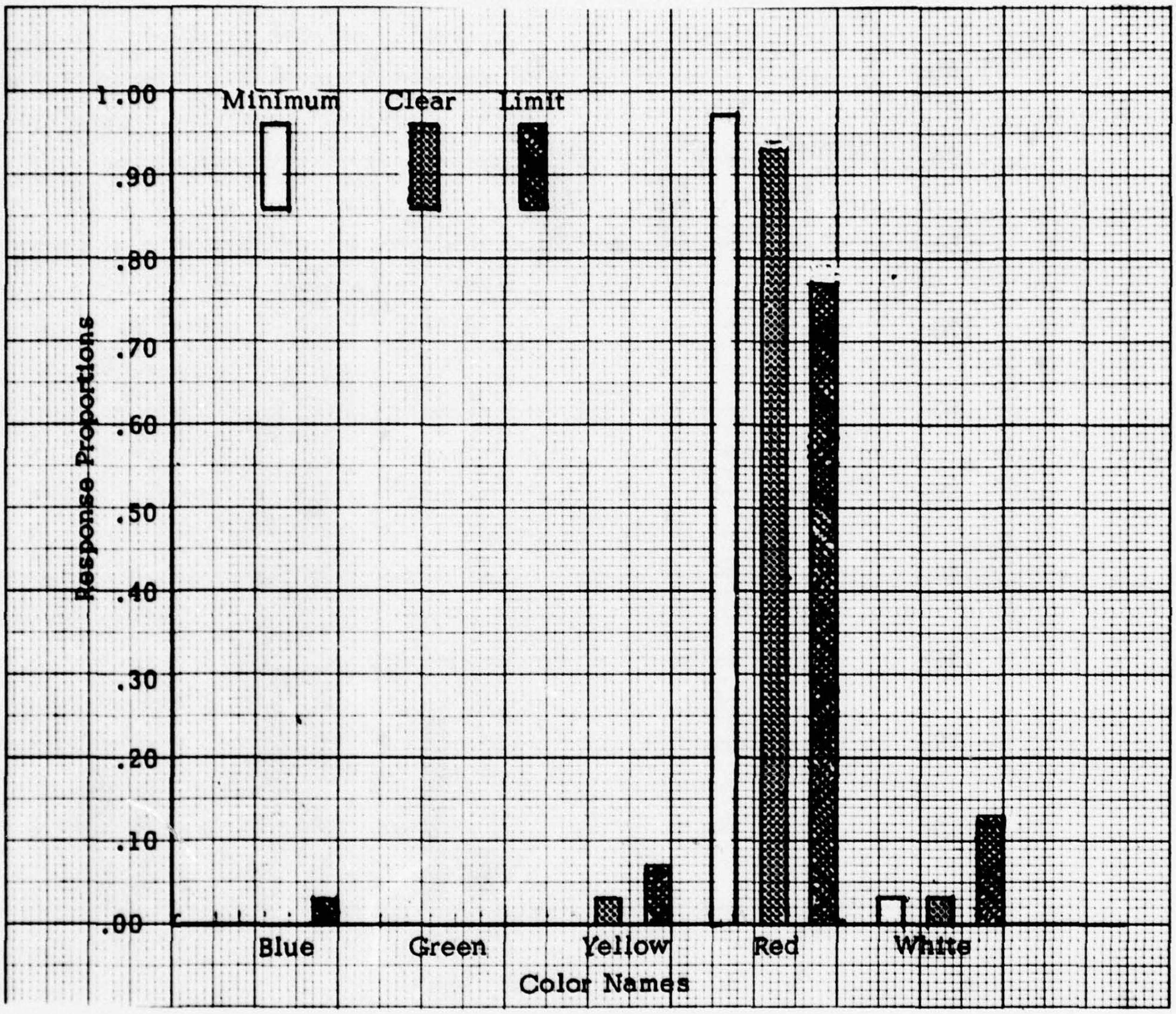

Figure 10. Distribution of Color-Name Scores in 'Ocean' Turbidity At Three Levels of Display Legibility: 640 nm Stimulus

Table 17. Distribution of Color-Name Scores At Three Levels of Display Legibility: 'Ocean' Turbidity

Stimulus Wavelength	Stimulus Intensity	Color Name				
		Blue	Green	Yellow	Red	White
White	Minimum	-	-	.40	.17	.43
	Clear	-	.03	.33	.03	.60
	Limit	-	.03	.17	.03	.77
473 nm	Minimum	.60	.03	-	-	.37
	Clear	.83	.07	-	-	.10
	Limit*	.93	-	-	-	.07
503 nm	Minimum	.30	.70	-	-	-
	Clear	.30	.67	.03	-	-
	Limit**	.17	.77	.03	-	.03
552 nm	Minimum	.13	.47	.10	-	.30
	Clear	.07	.63	.03	-	.27
	Limit	.03	.57	.37	-	.03
579 nm	Minimum	-	.10	.43	.07	.40
	Clear	-	.07	.47	.03	.43
	Limit	-	.03	.70	-	.27
608 nm	Minimum	-	-	.03	.87	.10
	Clear	-	-	.07	.77	.17
	Limit	-	-	.23	.60	.17
640 nm	Minimum	-	-	-	.97	.03
	Clear	-	-	.03	.93	.03
	Limit	.03	-	.07	.77	.13

*3.45 ft-L
**14.52 ft-L

b. <u>In 'Harbor' Turbidity</u>. Six wavelengths were compared at two levels of luminance defining 'Minimum' and 'Clear' legibility (mean luminances at the source display were 7.6 and 34.3 ft-L, respectively). The 503 nm stimulus was included in this analysis by moving the display closer to the observer until the 'Clear' display legibility criterion was achieved. Omitted from the analysis was the 473 nm stimulus which could be made minimally legible but not clearly legible by this procedure. None of the stimuli could be made bright enough to determine an upper luminance boundary for 'Limit' legibility.

Color names in 'Harbor' turbidity were not significantly affected by the difference in display luminance between 'Minimum' and 'Clear' legibility. Color-name score distributions are shown in Table 18.

Table 18. Distribution of Color-Name Scores At Two Levels of Display Legibility: 'Harbor' Turbidity

Stimulus Wavelength	Stimulus Intensity	Color Name				
		Blue	Green	Yellow	Red	White
White	Minimum	-	-	.40	.30	.30
	Clear	-	-	.57	.13	.30
503 nm	Minimum	.27	.60	-	-	.13
	Clear	.30	.63	-	-	.07
552 nm	Minimum	.20	.47	.10	-	.23
	Clear	.10	.67	.10	-	.13
579 nm	Minimum	.07	.10	.37	.07	.40
	Clear	-	.07	.47	.03	.43
608 nm	Minimum	-	-	.17	.70	.13
	Clear	-	-	.30	.63	.07
640 nm	Minimum	-	-	.03	.93	.03
	Clear	-	-	.03	.97	-

IV. SUMMARY AND APPLICATION OF RESULTS

A. Luminance Requirements

The luminance required of a self-luminous display varied with water turbidity, display size and legibility criterion. The experimental display could not be made sufficiently bright to determine the upper limits of display luminance required in a 'Harbor' turbidity environment, otherwise the range of luminance values required for the remaining combinations of viewing conditions was rather narrow: between 0.07 and 40.0 ft-L. Figure 11 shows values of luminances required for the several combinations of display size, legibility criterion and turbidity condition addressed in the experiment. These results apply to dark-adapted observers, viewing displays in dark ambient underwater environments.

From Figure 11 the orders of magnitude of the main effects on luminance requirements can be roughly assessed as follows:

- The effect of the turbidity variable was to increase display luminance requirements (as measured at the display) by approximately 1.5 log units for comparable display sizes at comparable legibility criteria.
- The effect of the legibility criteria (excluding the 'Limit' criterion) was approximately 1.0 log unit of luminance in the 'Ocean', but only 0.5 log unit for the 'Harbor' turbidity condition.
- The effect of display size differences was approximately 0.5 log unit of luminance. The larger displays required less luminance than the smaller for equivalent legibility in both turbidity media.

Two comparisons of the present data with those collected in 1977 were of interest. First the luminance values at 'threshold' legibility as determined in 1977 were compared with the 'Minimum' legibility values obtained in the present experiment and found to be discrepant by about 1.0 log unit. Second, the significant effects of display wavelength in the earlier work were not significant in the present. In the previous experiment, threshold values of luminance were determined by a method of limits procedure and the observers

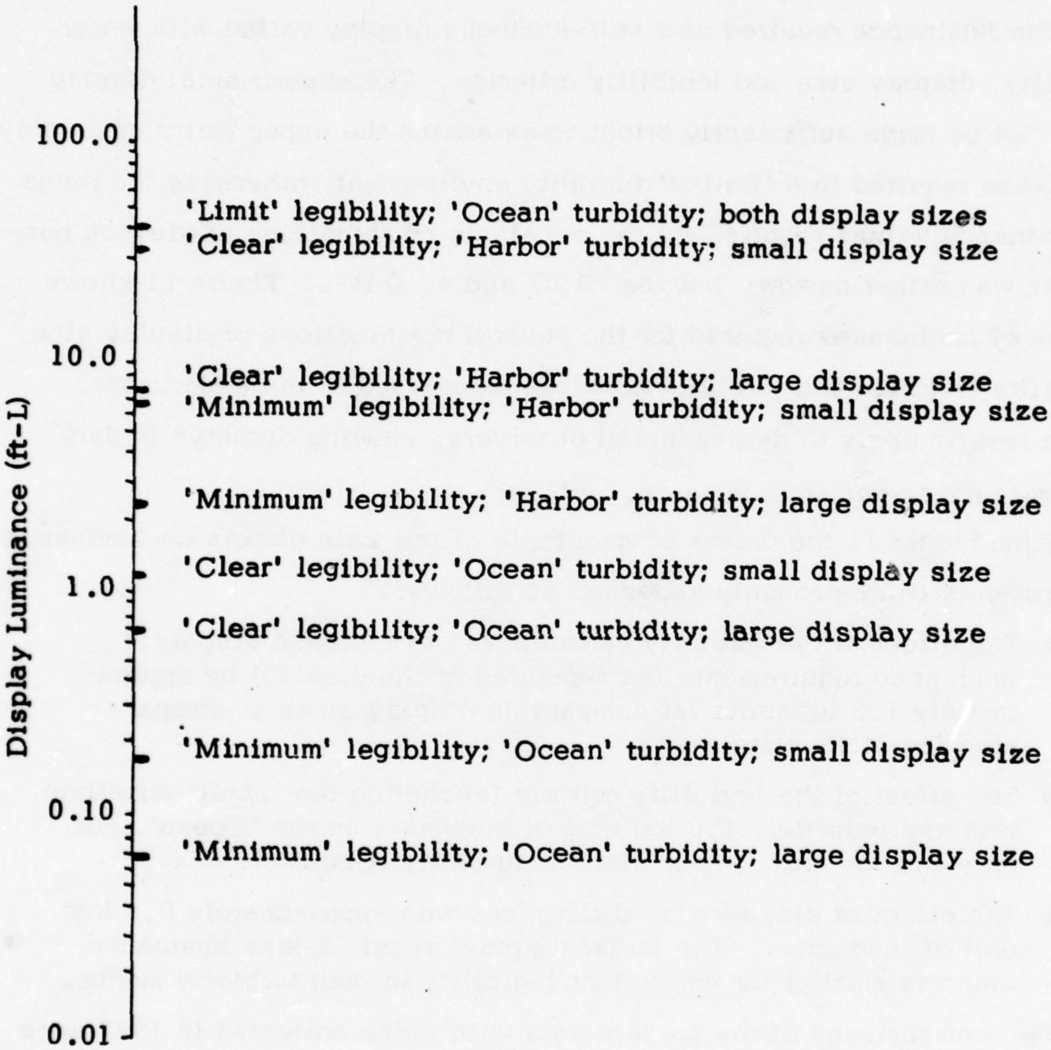

Figure 11. Luminance Requirements (ft-L) for Combinations of Experimental Conditions

were instructed appropriately. Consequently, legible luminances were lower than in the present experiment where observers were instructed to respond according to more operationally-oriented legibility criteria. The differences in data collection procedures and response criteria resulted in a 1.0 log unit difference in values between 'threshold' legibility (1977) and 'minimum' legibility (1978). Table 19 presents some comparative data.

Table 19. Comparative Luminances (ft-L) At 'Threshold' and 'Minimum' Legibility

	'Threshold'	'Minimum'
'Ocean' at 25 cm		
Overall Mean	0.007	0.12
Size Effects		
Large	0.005	0.07
Small	0.012	0.16
'Harbor' at 25 cm		
Overall Mean	0.40	5.06
Size Effects		
Large	0.20	2.34
Small	0.70	7.60

The differences in levels of display luminance associated with 'threshold' (1977) vs 'minimum' (1978) legibility criteria account for the non-significant effects of wavelength in the present experiment. Levels of luminance required for 'threshold' legibility in 'Ocean' turbidity, for example, were in the range 0.005 to 0.01 ft-L as compared to the 0.07 to 0.16 ft-L range required for the

'Minimum' legibility criterion. At the lower luminances, the rod receptor contribution to legibility was significant and the luminance requirements as a function of wavelength tended to track the luminosity of rod vision.

B. Color Appearances

In the dark, color appearances of the seven stimuli were remarkably stable over variations in water turbidity and display size. When display luminance was adequate for 'Clear' legibility, only the White and the 608 nm stimuli were significantly affected by turbidity differences; the 579 nm wavelength stimulus, by differences in display size. Color appearance shifts with luminance at the boundaries of legibility were more numerous; all but the 503 nm display were affected.

The effect of the 'Harbor' turbidity condition was to shift the 'white' component of a display's color appearance toward 'yellow'. In the relatively clear 'Ocean' medium, the modal color-name response to the White stimulus was 'white/yellow'; in the 'Harbor' turbidity, it was 'yellow'. Similarly, the 608 nm stimulus was called principally by combinations of 'red' and 'white' color names in the 'Ocean', and by combinations of 'red' and 'yellow' in the 'Harbor'.

Display size differences significantly altered the color appearance of the 579 nm display in the 'Ocean' environment. At 23' visual angle the display appeared 'yellow'; at 41', a highly desaturated yellow (either'white/yellow' or 'yellow/white').

The effect of a full range of luminance variations could be assessed only in the 'Ocean' viewing medium, where three categories of color appearance shifts occurred in the luminance range .07 to 40.0 ft-L. White, 473 nm and 579 nm stimuli appeared to increase in saturation as intensity increased. White appeared more uniquely 'white', 473 nm more uniquely 'blue' and 579 nm more uniquely 'yellow' as display luminance increased. The main shift in appearance of the 579 nm stimulus occurred at the 40.0 ft-L level

of display luminance while the saturation of White and 473 nm occurred at 0.70 ft-L. This finding is in accord with results obtained by Hill, 1947, (as reported by Grether and Baker, 1972) in a study of color identification of point-source signal lights. As compared to red, green and white light, yellow required greater intensity for 90% accurate color identification.

The Bezold-Brücke phenomenon accounted for shifts in the color appearance of the 552 nm and 608 nm displays between 0.70 and 40.0 ft-L luminance. The 552 nm display shifted from 'green/white' to 'green/yellow', the 608 nm display shifted from 'red/white' to 'red/yellow'.

The 640 nm display appeared desaturated at 40.0 ft-L as compared to its color appearances at the 0.07 and 0.70 ft-L intensities. Seen as 'red' and only 'red' at the two lower luminances, the 640 nm display was called 'red/white' at 40.0 ft-L.

C. Applications

Self-luminous displays are required to be legible in both 'Ocean' and 'Harbor' environments. A range of 0.07 to 40.0 ft-L luminance satisfied this requirement when the display console is assumed at 25 cm from the faceplate, the observer is dark adapted, the viewing environment is dark (i.e., displays are at a brightness contrast ratio approximating infinity) and the 'Harbor' turbidity approximates that of the Chesapeake Bay at depths of 5-10 meters. Additional luminance will be needed to overcome greater concentrations of suspended particles characteristic of greater depths.

Use of colored displays underwater may need to consider the effects of changes in viewing conditions on their appearance; particularly for applications where absolute color identification is required. A display that appears 'white' in a clear, oceanic water environment may appear 'yellow' in turbid water. A 579 nm display will appear reliably 'yellow' only at high intensity and small display size relative to other colored stimuli. A 608 nm wavelength-dominant display may appear 'red/white' in oceanic waters at low and

mid-range intensities, but 'red/yellow' at high intensity; and also 'red/yellow' in 'Harbor' turbidity conditions.

The 503 nm wavelength display was most consistent in color appearance, 'green/blue', although the upper boundary of display luminance for this stimulus was only 14.52 ft-L; and, therefore, potential effects of high intensity could not be determined.

Those displays whose color appearances were not affected by either display size or water turbidity differences can be expected to shift with differences in luminance. Table 20 lists the modal color name for those four stimuli at three legible intensities. The optimum level of display intensity is tabled as 'Clear'; the lower and upper limits are tabled 'Minimum' and 'Limit'.

Table 20. Color Names for Four Wavelengths Invariant with Display Size and Water Turbidity

Stimulus Wavelength (nm)	Legibility Criteria		
	'Minimum'	'Clear'	'Limit'
473 nm	Blue/White	Blue	Blue
503 nm	Green/Blue	Green/Blue	Green/Blue
552 nm	Green/White	Green/White	Green/Yellow
640 nm	Red	Red	Red/White

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APPENDIX A

OPTICAL DENSITY MEASUREMENTS AND ANALYSES OF 'OCEAN' AND 'HARBOR' TURBIDITY SIMULATIONS

Table A-1. Optical Density of 'Ocean' Turbidity Simulations

Wavelength (nm)	Water Samples					Mean	Standard Deviation
	27 Feb 78	28 Feb 78	1 Mar 78	2 Mar 78	3 Mar 78		
470	.06	.10	.08	.05	.06	.070	.0200
480	.06	.09	.08	.05	.06	.068	.0164
490	.06	.09	.08	.05	.06	.068	.0164
500	.06	.09	.07	.05	.05	.064	.0167
510	.06	.09	.07	.05	.05	.064	.0167
520	.06	.09	.07	.05	.05	.064	.0167
530	.05	.08	.06	.05	.05	.058	.0130
540	.05	.08	.06	.04	.05	.056	.0152
550	.05	.08	.06	.04	.05	.056	.0152
560	.05	.08	.06	.04	.05	.056	.0152
570	.05	.07	.06	.04	.05	.054	.0114
580	.05	.07	.06	.04	.04	.052	.0130
590	.05	.07	.06	.04	.04	.052	.0130
600	.04	.06	.05	.04	.04	.046	.0089
610	.04	.06	.05	.03	.04	.044	.0114
620	.04	.06	.05	.03	.03	.042	.0130
630	.03	.05.	.04	.02	.03	.034	.0114
640	.03	.05	.04	.02	.03	.034	.0114

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Table A-2. Optical Density of 'Harbor' Turbidity Simulations

Wavelength (nm)	Water Samples					Mean	Standard Deviation
	6 Mar 78	7 Mar 78	8 Mar 78	9 Mar 78	13 Mar 78		
470	.86	.49	.80	.53	.43	.622	.1943
480	.86	.49	.79	.52	.42	.616	.1958
490	.85	.48	.79	.52	.42	.612	.1943
500	.85	.48	.78	.51	.41	.606	.1958
510	.85	.48	.77	.51	.41	.604	.1936
520	.85	.47	.77	.51	.40	.600	.1977
530	.83	.47	.76	.50	.40	.592	.1904
540	.82	.46	.75	.49	.39	.582	.1904
550	.81	.45	.75	.48	.38	.574	.1927
560	.80	.45	.74	.47	.38	.568	.1886
570	.79	.44	.72	.47	.37	.558	.1851
580	.78	.43	.71	.46	.36	.548	.1851
590	.77	.43	.70	.45	.35	.540	.1836
600	.76	.41	.69	.44	.34	.528	.1851
610	.75	.40	.67	.43	.33	.516	.1830
620	.73	.39	.66	.42	.33	.506	.1733
630	.72	.38	.64	.41	.33	.496	.1727
640	.70	.37	.63	.40	.32	.484	.1695

Table A-3. Mean Optical Density At Selected Wavelengths for Samples of Artificially Turbid 'Ocean' Water Prepared in 1976, 1977 and 1978

Wavelength (nm)	Year		
	1978	1977	1976
500	.064	.087	.152
510	.064	.084	.146
520	.064	.082	.140
530	.058	.079	.134
540	.056	.077	.131
550	.056	.075	.124
560	.056	.073	.120
570	.054	.072	.115
580	.052	.070	.112
590	.052	.068	.109
600	.046	.067	.104

Table A-4. Mean Optical Density At Selected Wavelengths for Samples of Artificially Turbid 'Harbor' Water Prepared in 1976, 1977 and 1978

Wavelength (nm)	Year		
	1978	1977	1976
500	.606	.696	.748
510	.604	.691	.739
520	.600	.686	.735
530	.592	.680	.726
540	.582	.669	.721
550	.574	.660	.711
560	.568	.650	.700
570	.558	.642	.688
580	.548	.633	.682
590	.540	.621	.670
600	.528	.610	.661

APPENDIX B

TEST PARTICIPANTS

Name	Rank/Rate
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Baron, Timothy A.	QM1
Birtz, Pierre P.	ENC
Coulter, Daley T.	LT
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Peters, Richard R.	QM2
Rodgers, Francis X.	AT3
Rue, James D.	BT1
Sweesy, Clayton J.	BM1

APPENDIX C

BASIC DATA TABLES OF LUMINANCE REQUIREMENTS (FT-L) FOR LEGIBILITY OF SEVEN COLORED DISPLAYS AT TWO DISPLAY SIZES IN 'OCEAN' AND 'HARBOR' VIEWING ENVIRONMENTS

Table C-1. Luminance Requirements (ft-L) for Legibility of Seven Colored Displays in 'Ocean' Turbidity

Observers	White Display					
	Minimum		Clear		Limit	
	23'	41'	23'	41'	23'	41'
1	.159	.076	.547	.462	2.642	15.531
2	.121	.067	.929	.316	66.400	39.839
3	.196	.079	.592	.353	64.762	66.400
4	.209	.037	1.996	.520	54.801	22.889
5	.233	.145	2.299	.833	66.400	53.534
6	.125	.037	1.769	.254	10.694	66.400
7	.132	.156	1.382	.623	66.400	60.190
8	.167	.045	1.696	.616	66.400	66.400
9	.076	.061	.520	.598	66.400	66.400
10	.161	.086	.558	.395	66.400	2.763
$\bar{X}$	.160	.080	1.230	.500	53.13	46.03
σ	.050	.040	.680	.180	24.82	24.25

Table C-1. Luminance Requirements (ft-L) for Legibility of Seven Colored Displays in 'Ocean' Turbidity (Continued)

Observers	473 nm Display				503 nm Display			
	Minimum		Clear		Minimum		Clear	
	23'	41'	23'	41'	23'	41'	23'	41'
1	.296	.090	2.097	.334	.252	.076	1.272	.235
2	.239	.093	2.126	.563	.125	.062	.673	.773
3	.157	.097	1.260	.330	.087	.117	.374	.474
4	.101	.043	3.450	3.331	.179	.032	1.724	.291
5	.163	.104	2.880	.706	.134	.072	2.200	.463
6	.145	.042	1.058	.146	.080	.069	.812	1.351
7	.145	.091	3.450	3.450	.097	.045	1.015	.486
8	.173	.036	.658	.622	.121	.034	.994	.307
9	.138	.100	1.164	1.164	.103	.038	2.690	1.173
10	.141	.117	2.156	.431	.314	.101	.509	.362
$\bar{X}$	.170	.080	2.030	1.110	.150	.060	1.230	.590
σ	.060	.030	1.000	1.230	.080	.030	.760	.390

Table C-1. Luminance Requirements (ft-L) for Legibility of Seven Colored Displays in 'Ocean' Turbidity (Continued)

Observers	552 nm Display					
	Minimum		Clear		Limit	
	23'	41'	23'	41'	23'	41'
1	.155	.070	.700	.473	11.020	
2	.195	.127	2.678	.886	14.500	
3	.225	.039	1.550	.171	33.619	
4	.088	.035	1.071	.290	7.672	
5	.134	.076	.723	.663	48.749	
6	.074	.035	1.361	.477	49.300	
7	.121	.064	.522	.877	20.802	
8	.067	.023	1.029	.114	49.100	
9	.101	.101	1.093	.779	49.300	
10	.231	.069	1.932	.372	12.757	
$\bar{X}$	.140	.060	1.270	.510	29.68	
σ	.060	.030	.650	.280	18.12	

Table C-1. Luminance Requirements (ft-L) for Legibility of Seven Colored Displays in 'Ocean' Turbidity (Continued)

Observers	579 nm Display					
	Minimum		Clear		Limit	
	23'	41'	23'	41'	23'	41'
1	.194	.067	1.046	.135	10.852	3.462
2	.145	.103	.554	.585	4.057	3.010
3	.181	.224	.629	1.977	48.410	55.200
4	.120	.031	1.156	.273	5.302	47.037
5	.213	.083	2.023	.540	55.200	55.200
6	.088	.045	1.977	1.189	29.760	55.200
7	.174	.056	1.491	1.139	10.544	19.393
8	.046	.030	.234	2.023	4.390	55.200
9	.134	.046	3.497	.331	55.200	6.494
10	.094	.056	.410	.366	55.200	39.158
$\bar{X}$	.140	.070	1.300	.860	27.89	33.94
σ	.050	.060	1.690	.700	23.29	23.23

Table C-1. Luminance Requirements (ft-L) for Legibility of Seven Colored Displays in 'Ocean' Turbidity (Continued)

Observers	608 nm Display					
	Minimum		Clear		Limit	
	23'	41'	23'	41'	23'	41'
1	.676	.095	2.040	.245	18.632	2.834
2	.095	.052	.789	.473	58.816	2.804
3	.135	.136	.522	.656	64.621	58.816
4	.083	.049	.752	.397	5.027	15.097
5	.141	.082	1.326	.604	49.392	4.751
6	.059	.036	.330	.473	65.700	63.948
7	.125	.068	.517	.789	6.170	65.700
8	.074	.048	.522	2.192	65.700	65.700
9	.145	.084	1.607	.723	45.680	65.700
10	.199	.077	.563	.243	14.429	5.760
$\bar{X}$	.170	.070	.900	.680	39.420	35.110
σ	.180	.030	.570	.560	25.550	30.680

Table C-1. Luminance Requirements (ft-L) for Legibility of Seven Colored Displays in 'Ocean' Turbidity (Continued)

Observers	640 nm Display					
	Minimum		Clear		Limit	
	23'	41'	23'	41'	23'	41'
1	.196	.065	.556	.165	8.767	1.739
2	.208	.073	1.680	.531	12.505	3.912
3	.252	.085	1.865	.679	47.055	49.800
4	.177	.044	3.835	.805	49.800	49.800
5	.239	.213	3.650	1.045	46.129	5.979
6	.112	.045	1.143	.536	49.800	4.431
7	.233	.082	1.290	1.131	49.800	49.800
8	.084	.072	2.581	.382	49.800	49.800
9	.156	.106	1.505	.750	49.800	49.800
10	.268	.078	.797	.165	36.514	3.157
$\bar{X}$	.190	.090	1.890	.620	40.000	26.820
σ	.060	.050	1.130	.330	16.020	24.240

Table C-2. Luminance Requirements (ft-L) for Legibility of Seven Colored Displays in 'Harbor' Turbidity

Observers	White Display				473 nm Display
	Minimum		Clear		Minimum
	41'	82'	41'	82'	82'
1	7.066	2.926	63.843	8.659	2.374
2	5.641	2.251	64.762	17.923	--
3	3.687	1.889	28.448	6.127	3.450
4	4.465	1.828	46.526	5.140	1.932
5	8.366	1.479	50.494	4.514	2.802
6	3.449	1.479	16.405	6.758	1.555
7	6.064	1.343	27.969	3.515	2.509
8	2.860	1.281	8.962	6.988	3.450
9	21.863	1.788	66.400	8.759	2.003
10	7.388	4.092	43.605	12.650	---
$\bar{X}$	7.080	2.010	41.740	8.100	2.510
σ	5.500	.840	20.580	4.310	.690

Table C-2. Luminance Requirements (ft-L) for Legibility of Seven Colored Displays in 'Harbor' Turbidity (Continued)

Observers	503 Display			552 nm Display			
	Minimum		Clear	Minimum		Clear	
	41'	82'	82'	41'	82'	41'	82'
1	8.335	3.059	11.751	4.750	3.215	36.208	10.448
2	10.517	4.776	14.520	7.780	2.147	48.400	15.451
3	6.740	3.285	10.287	6.505	1.258	22.506	5.967
4	9.950	1.789	3.147	12.299	2.788	42.232	7.360
5	8.335	2.482	10.517	4.467	2.303	23.409	5.193
6	7.629	1.543	9.435	5.677	1.794	18.402	2.572
7	9.270	1.811	6.156	11.223	2.001	23.409	9.266
8	11.571	6.500	14.520	6.426	2.572	15.699	6.426
9	9.604	2.113	14.520	5.259	1.452	25.326	9.144
10	14.520	3.923	14.520	9.144	3.824	33.002	12.526
$\bar{X}$	8.760	3.130	10.940	7.350	2.330	28.860	8.430
σ	3.380	1.570	3.920	2.720	.790	10.680	3.760

Table C-2. Luminance Requirements (ft-L) for Legibility of Seven Colored Displays in 'Harbor' Turbidity (Continued)

Observers	579 nm Display				608 nm Display			
	Minimum		Clear		Minimum		Clear	
	41'	82'	41'	82'	41'	82'	41'	82'
1	4.341	1.798	49.823	7.838	4.032	1.992	18.632	7.849
2	5.974	1.817	46.071	9.400	6.241	2.245	61.329	12.221
3	6.812	2.793	13.697	9.956	4.165	1.299	13.179	5.085
4	4.708	1.491	55.200	3.393	3.780	1.273	30.658	2.690
5	5.974	1.798	22.238	4.938	5.505	1.854	29.542	3.989
6	4.244	1.599	21.860	14.433	3.081	1.367	15.797	7.328
7	11.828	1.914	40.782	6.893	21.800	1.497	49.392	6.534
8	6.266	1.742	43.641	4.057	4.032	1.624	27.984	5.321
9	32.777	1.977	55.200	18.110	17.075	1.836	65.700	5.085
10	8.932	5.495	32.777	6.494	9.755	6.841	63.282	22.192
$\bar{X}$	9.190	2.240	38.130	8.550	7.950	2.180	37.550	7.830
σ	8.600	1.200	14.770	4.670	6.440	1.670	20.520	5.680

Table C-2. Luminance Requirements (ft-L) for Legibility of Seven Colored Displays in 'Harbor' Turbidity (Continued)

Observers	640 nm Display			
	Minimum		Clear	
	41'	82'	41'	82'
1	3.509	1.372	23.757	5.766
2	2.867	1.430	32.200	11.082
3	2.406	1.537	14.610	3.331
4	4.592	2.155	12.900	3.798
5	8.897	1.372	29.040	3.912
6	2.382	1.077	12.900	4.379
7	10.762	5.427	25.184	11.082
8	3.124	1.372	26.697	3.509
9	8.897	2.382	49.800	11.411
10	6.430	3.650	24.699	11.934
$\bar{X}$	5.390	2.180	25.180	7.020
σ	3.130	1.37	11.000	3.810

APPENDIX D

BASIC DATA TABLES OF COLOR APPEARANCE SCORES FOR SEVEN COLORED DISPLAYS AT TWO DISPLAY SIZES IN 'OCEAN' AND 'HARBOR' VIEWING ENVIRONMENTS

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment

1. Color Appearance of A White Stimulus

Observer	Small Digit Size: 3 mm at 45 cm (23')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2			1		2			1		2			1	
2	3					3					2			1	
3			1	2				1	2		1			2	
4	2			1		1			2					3	
5	2			1		2			1		2			1	
6	2				1	2				1	2			1	
7	2				1	2				1	3				
8				3					3		3				
9	2				1	2			1		3				
10				3					3		3				
Total	15		1	11	3	14		1	13	2	21			9	
p	.50		.03	.37	.10	.47		.03	.43	.07	.70			.30	

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

1. Color Appearance of A White Stimulus (Continued)

Observer	Large Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2			1		2			1		2			1	
2	1			2		3					2			1	
3	2				1	2		1			2				1
4	2			1		2			1		2			1	
5	2			1		2			1		2			1	
6				2	1				3		2		1		
7	2			1		2			1		2			1	
8					3	2				1	3				
9	2			1		2			1		3				
10				3		1			2		3				
Total	13			12	5	18		1	10	1	23		1	5	1
p	.43			.40	.17	.60		.03	.33	.03	.77		.03	.17	.03

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

2. Color Appearance of 473 nm Stimulus

Observer	Small Digit Size: 3 mm at 45 cm (23')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1		3					3					3			
2		1	2				3					3			
3		3					2	1				3			
4		3				1	2				1	2			
5		3					3					3			
6		3					3					3			
7		2	1				3					3			
8			3			1	2					3			
9		3					3					3			
10			3				2	1				2	1		
Total		21	9			2	26	2			1	28	1		
p		.70	.30			.07	.87	.07			.03	.93	.03		

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

2. Color Appearance of 473 nm Stimulus (Continued)

Observer	Large Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2	1				2	1				1	2			
2	2	1					3					3			
3		2	1				3					3			
4		3					3					3			
5		3					3					3			
6		3					3				1	2			
7		3					3					3			
8	3						1	2				3			
9	1	2				1	2					3			
10	3						3					3			
Total	11	18	1			3	25	2			2	28			
p	.37	.60	.03			.10	.83	.07			.07	.93			

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

3. Color Appearance of 503 nm Stimulus

Observer	Small Digit Size: 3 mm at 45 cm (23')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1			3					3					3		
2	2		1					3					3		
3		2	1				2	1				1	2		
4		1	2				2	1					3		
5			3					3					3		
6	2		1					3					3		
7			3				1	2				1	2		
8			2	1				2	1				2	1	
9			3				1	2				1	2		
10		1	2				1	2				1	2		
Total	4	4	21	1			7	22	1			4	25	1	
p	.13	.13	.70	.03			.23	.73	.03			.13	.83	.03	

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

3. Color Appearance of 503 nm Stimulus (Continued)

Observer	Large Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1			3					3					3		
2			3				1	2				1	2		
3		2	1				2	1					3		
4		2	1				1	2			1		2		
5			3					3					3		
6			3					3					2	1	
7		2	1				2	1				1	2		
8		1	2					2	1				3		
9			3				1	2				1	2		
10		2	1				2	1				2	1		
Total		9	21				9	20	1		1	5	23	1	
p		.30	.70				.30	.67	.03		.03	.17	.77	.03	

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

4. Color Appearance of 552 nm Stimulus

Observer	Small Digit Size: 3 mm at 45 cm (23')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2		1			1		2			1		2		
2	2		1			1		2					2	1	
3		1	2				1	2					2	1	
4		2	1			1	2						1	2	
5			2	1				2	1				2	1	
6	2		1					3					3		
7	1		2					3					2	1	
8	3								3					3	
9	2		1				1	2					2	1	
10			3					3					3		
Total	12	3	14	1		3	4	19	4		1		19	10	
p	.40	.10	.47	.03		.10	.13	.63	.13		.03		.63	.33	

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

4. Color Appearance of 552 nm Stimulus (Continued)

Observer	Large Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	3					2		1					2	1	
2	1		2			1		2					2	1	
3		2	1				1	2					1	2	
4	1	2				1		2					1	2	
5			3					3					3		
6			3					3					2	1	
7			3					2	1				2	1	
8	3					3								3	
9	1		2			1		2			1		2		
10				3			1	2				1	2		
Total	9	4	14	3		8	2	19	1		1	1	17	11	
p	.30	.13	.47	.10		.27	.07	.63	.03		.03	.03	.57	.37	

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

5. Color Appearance of 579 nm Stimulus

Observer	Small Digit Size: 3 mm at 45 cm (23')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1				3					3					3	
2	2			1					3				1	2	
3			1	2				1	2					3	
4	2				1	2				1				3	
5				3					3					3	
6	2			1					3				1	2	
7				2	1				2	1				3	
8				2	1				2	1				3	
9	2		1			2			1		2			1	
10				3		1			2		3				
Total	8		2	17	3	5		1	21	3	5		2	23	
p	.27		.07	.57	.10	.17		.03	.70	.10	.17		.07	.77	

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

5. Color Appearance of 579 nm Stimulus (Continued)

Observer	Large Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2			1		2			1					3	
2	3					3					1			2	
3	2		1			1		2			3				
4			2	1					3					3	
5				3					3					3	
6				2	1				2	1			1	2	
7	3					3								3	
8				2	1				3					3	
9	2			1		2			1		1			2	
10				3		2			1		3				
Total	12		3	13	2	13		2	14	1	8		1	21	
p	.40		.10	.43	.07	.43		.07	.47	.03	.27		.03	.70	

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

6. Color Appearance of 608 nm Stimulus

Observer	Small Digit Size: 3 mm at 45 cm (23')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1				2	1				2	1				1	2
2	1				2	1				2				2	1
3					3	1				2				2	1
4				1	2				1	2				2	1
5				1	2					3					3
6					3					3					3
7				1	2				1	2				1	2
8					3					3					3
9				1	2				1	2				1	2
10					3					3					3
Total	1			6	23	2			5	23				9	21
p	.03			.20	.77	.07			.17	.77				.30	.70

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

6. Color Appearance of 608 nm Stimulus (Continued)

Observer	Large Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2				1	2				1				1	2
2					3				1	2				2	1
3					3	1				2	2				1
4					3					3				2	1
5				1	2				1	2				1	2
6					3					3				1	2
7					3	1				2	1				2
8					3					3	1				2
9	1				2	1				2	1				2
10					3					3					3
Total	3			1	26	5			2	23	5			7	18
p	.10			.03	.87	.17			.07	.77	.17			.23	.60

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

7. Color Appearance of 640 nm Stimulus

Observer	Small Digit Size: 3 mm at 45 cm (23')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	1				2	1				2					3
2					3					3					3
3					3				1	2	1				2
4					3					3					3
5					3					3					3
6					3					3					3
7					3					3		1			2
8				1	2					3					3
9	1				2				1	2		1			2
10				1	2					3					3
Total	2			2	26	1			2	27	1	2			27
p	.07			.07	.87	.03			.07	.90	.03	.07			.90

Table D-1. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Ocean' Viewing Environment (Continued)

7. Color Appearance of 640 nm Stimulus (Continued)

Observer	Large Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	1				2	1				2					3
2					3				1	2				1	2
3					3					3	1				2
4					3					3	1				2
5					3					3					3
6					3					3					3
7					3					3		1			2
8					3					3	1				2
9					3					3	1				2
10					3					3				1	2
Total	1				29	1			1	28	4	1		2	23
p	.03				.97	.03			.03	.93	.13	.03		.07	.77

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment

1. Color Appearance of A White Stimulus

Observer	Small Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	1			2					3					3	
2	1				2				3					3	
3				3					3				1	2	
4				2	1	1			2		1			2	
5	2				1	2				1	2				1
6					3				1	2				2	1
7	1			2		1			2		1			2	
8				3					3		1			2	
9	1				2	2				1	2				1
10	3					3					3				
Total	9			12	9	9			17	4	10		1	16	3
p	.30			.40	.30	.30			.57	.13	.33		.03	.53	.10

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LUMINANCE REQUIREMENTS AND COLOR APPEARANCES OF COLORED DISPLAY--ETC(U)
DEC 78 W S VAUGHAN, R A GLASS, J WILLIAMS N00014-74-C-0276

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Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

1. Color Appearance of A White Stimulus (Continued)

Observer	Large Digit Size: 6 mm at 25 cm (82')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2			1					3					3	
2	1				2	1				2	2				1
3			1	2				1	2					3	
4				1	2				1	2				2	1
5	1			2		2			1		3				
6					3					3				2	1
7				2	1				2	1				2	1
8					3					3				1	2
9	2				1	2				1	2				1
10				3					3					3	
Total	6		1	11	12	5		1	12	12	7			16	7
p	.20		.03	.37	.40	.17		.03	.40	.40	.23			.53	.23

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

2. Color Appearance of 473 nm Stimulus

Observer	Small Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1		3													
2		3													
3		2	1												
4		3													
5	2	1													
6			3												
7		3													
8	1	2													
9	3														
10		3													
Total	6	20	4												
p	.20	.67	.13												

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

2. Color Appearance of 473 nm Stimulus (Continued)

Observer	Large Digit Size: 6 mm at 25 cm (82')														
	Minimum Legibility					Clear Legibility					Limiti Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2	1													
2		2	1												
3		2	1												
4		3													
5		3													
6			3												
7		3													
8	3														
9	2	1													
10	1	2													
Total	8	17	5												
p	.27	.57	.17												

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

3. Color Appearance of 503 nm Stimulus

Observer	Small Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2		1					3							
2		3					3								
3		1	2				1	2							
4		2	1				1	2							
5			3				1	2							
6			3					3							
7			3					3							
8	1	2				1	2								
9	1		2			1		2							
10			3				1	2							
Total	4	8	18			2	9	19							
p	.13	.27	.60			.07	.30	.63							

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

3. Color Appearance of 503 nm Stimulus (Continued)

Observer	Large Digit Size: 6 mm at 25 cm (82')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2	1						3					3		
2		3				1		2							
3		1	2				1	2							
4		3					3					2	1		
5		3						3					3		
6			3					3					3		
7			3					3					3		
8	2			1		2			1						
9	1		2			1		2							
10			3				1	2							
Total	5	11	13	1		4	5	20	1			2	13		
p	.17	.37	.43	.03		.13	.17	.67	.03			.07	.43		

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

4. Color Appearance of 552 nm Stimulus

Observer	Small Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2	1						3					3		
2	1	2					2	1				2	1		
3		1	2				1	2				1	2		
4		2	1					3					3		
5			2	1				2	1		1		2		
6			3					3					3		
7			3					3					3		
8	1			2		1			2		1			2	
9	3					3					3				
10			3					3					3		
Total	7	6	14	3		4	3	20	3		5	3	20	2	
p	.23	.20	.47	.10		.13	.10	.67	.10		.17	.10	.67	.07	

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

4. Color Appearance of 552 nm Stimulus (Continued)

Observer	Large Digit Size: 6 mm at 25 cm (82')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2	1				2		1			1		2		
2	1	2				1	2				1		2		
3		1	2				1	2					3		
4		3					2	1			1		2		
5			2	1				2	1				3		
6		1	2				1	2					3		
7	1		2					3					2	1	
8				3					3					3	
9	2		1			2		1			1		2		
10			3					3					3		
Total	6	8	12	4		5	6	15	4		4		22	4	
p	.20	.27	.40	.13		.17	.20	.50	.13		.13		.73	.13	

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

5. Color Appearance of 579 nm Stimulus

Observer	Small Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	1			2					3					3	
2				1	2	3					3				
3			2	1				2	1				2	1	
4	1	2				2			1		2			1	
5	2			1		2			1		2			1	
6			1	2					2	1			2	1	
7	1			2		1			2		1			2	
8	2			1					3					3	
9	2			1		2			1		2			1	
10	3					3					3				
Total	12	2	3	11	2	13		2	14	1	13		4	13	
p	.40	.07	.10	.37	.07	.43		.07	.47	.03	.43		.13	.43	

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

5. Color Appearance of 579 nm Stimulus (Continued)

Observer	Large Digit Size: 6 mm at 25 cm (82')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2			1		2			1					3	
2				3					3					3	
3			2	1				2	1				2	1	
4	1	2						1	2		1			2	
5	3					3					3				
6	1		2					2	1				2	1	
7				2	1				3					3	
8				3					3					3	
9	3					2			1		2			1	
10	3					3					3				
Total	13	2	4	10	1	10		5	15		9		4	17	
p	.43	.07	.13	.33	.03	.33		.17	.50		.30		.13	.57	

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

6. Color Appearance of 608 nm Stimulus

Observer	Small Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2				1				3					3	
2				1	2				2	1				2	1
3					3					3				1	2
4				1	2				2	1				2	1
5					3					3					3
6					3					3				1	2
7				2	1				1	2				1	2
8	1				2	1				2	1				2
9	1				2	1				2	1				2
10				1	2				1	2				1	2
Total	4			5	21	2			9	19	2			11	17
p	.13			.17	.70	.07			.30	.63	.07			.37	.57

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

6. Color Appearance of 608 nm Stimulus (Continued)

Observer	Large Digit Size: 6 mm at 25 cm (82')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	2				1				3					3	
2					3				1	2				1	2
3					3					3			1	2	
4				1	2				1	2				2	1
5					3					3					3
6					3				1	2			1	2	
7				1	2				2	1				2	1
8					3					3					3
9					3	1				2	1				2
10				1	2				2	1				2	1
Total	2			3	25	1			10	19	1		2	14	13
p	.07			.10	.83	.03			.33	.63	.03		.07	.47	.43

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

7. Color Appearance of 640 nm Stimulus

Observer	Small Digit Size: 3 mm at 25 cm (41')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1	1				2					3					3
2					3					3					3
3					3					3					3
4					3					3					3
5					3					3					3
6					3					3					3
7					3					3					3
8					3					3					3
9					3					3					3
10				1	2				1	2				2	1
Total	1			1	28				1	29				2	28
p	.03			.03	.93				.03	.97				.07	.93

Table D-2. Color Appearance Scores for Seven Wavelengths At Three Levels of Luminance in 'Harbor' Viewing Environment (Continued)

7. Color Appearance of 640 nm Stimulus (Continued)

Observer	Large Digit Size: 6 mm at 25 cm (82')														
	Minimum Legibility					Clear Legibility					Limit Legibility				
	W	B	G	Y	R	W	B	G	Y	R	W	B	G	Y	R
1					3					3					3
2					3	1				2				1	2
3					3					3					3
4					3					3					3
5					3					3					3
6					3					3					3
7					3					3					3
8					3					3					3
9					3					3					3
10				1	2				1	2				1	2
Total				1	29	1			1	28				2	28
p				.03	.97	.03			.03	.93				.07	.93

Table D-3. Proportional Distribution of Scores Across Color-Name Categories for A White Display and Six Narrow-Band Wavelength Displays

'White' at 'Minimum' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	.03	.37	.10	.50
Ocean (41')	-	-	.40	.17	.43
Harbor (41')	-	-	.40	.30	.27
Harbor (82')	-	.03	.37	.40	.20

'White' at 'Clear' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	.03	.43	.07	.42
Ocean (41')	-	.03	.33	.03	.60
Harbor (41')	-	-	.57	.13	.30
Harbor (82')	-	.03	.40	.40	.17

'White' at 'Limit' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	-	.30	-	.70
Ocean (41')	-	.03	.17	.03	.77

Table D-3. Proportional Distribution of Scores Across Color-Name Categories for A White Display and Six Narrow-Band Wavelength Displays (Continued)

473 nm at 'Minimum' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	.70	.30	-	-	-
Ocean (41')	.60	.03	-	-	.37
Harbor (41')	.67	.13	-	-	.20
Harbor (82')	.57	.17	-	-	.27

473 nm at 'Clear' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	.87	.07	-	-	.07
Ocean (41')	.83	.07	-	-	.10
Harbor (41')	-	-	-	-	-
Harbor (82')	-	-	-	-	-

473 nm at 'Limit' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	.93	.03	-	-	.03
Ocean (41')	.93	-	-	-	.07

Table D-3. Proportional Distribution of Scores Across Color-Name Categories for A White Display and Six Narrow-Band Wavelength Displays (Continued)

503 nm at 'Minimum' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	.13	.70	.03	-	.13
Ocean (41')	.30	.70	-	-	-
Harbor (41')	.27	.60	-	-	.13
Harbor (82')	.37	.43	.03	-	.17

508 nm at 'Clear' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	.23	.73	.03	-	-
Ocean (41')	.30	.67	.03	-	-
Harbor (41')	.30	.63	-	-	.07
Harbor (82')	.17	.67	.03	-	.13

508 nm at 'Limit' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	.13	.83	.03	-	-
Ocean (41')	.17	.77	.03	-	.03

Table D-3. Proportional Distribution of Scores Across Color-Name Categories for A White Display and Six Narrow-Band Wavelength Displays (Continued)

552 nm at 'Minimum' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	.10	.47	.03	-	.40
Ocean (41')	.13	.47	.10	-	.30
Harbor (41')	.20	.47	.09	-	.23
Harbor (82')	.27	.40	.13	-	.20

552 nm at 'Clear' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	.13	.63	.13	-	.10
Ocean (41')	.07	.63	.03	-	.27
Harbor (41')	.10	.67	.10	-	.13
Harbor (82')	.20	.50	.13	-	.17

552 nm at 'Limit' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	.63	.33	-	.03
Ocean (41')	.03	.57	.37	-	.03

Table D-3. Proportional Distribution of Scores Across Color-Name Categories for A White Display and Six Narrow-Band Wavelength Displays (Continued)

579 nm at 'Minimum' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	.07	.57	.10	.27
Ocean (41')	-	.10	.43	.07	.40
Harbor (41')	.17	.10	.37	.07	.40
Harbor (82')	.07	.13	.33	.03	.43

579 nm at 'Clear' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	.03	.70	.10	.17
Ocean (41')	-	.07	.47	.03	.43
Harbor (41')	-	.07	.47	.03	.43
Harbor (82')	-	.17	.50	-	.33

579 nm at 'Limit' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	.07	.77	-	.17
Ocean (41')	-	.03	.70	-	.27

Table D-3. Proportional Distribution of Scores Across Color-Name Categories for A White Display and Six Narrow-Band Wavelength Displays (Continued)

608 nm at 'Minimum' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	-	.20	.77	.03
Ocean (41')	-	-	.01	.87	.10
Harbor (41')	-	-	.17	.70	.13
Harbor (82')	-	-	.10	.83	.07

608 nm at 'Clear' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	-	.17	.77	.07
Ocean (41')	-	-	.07	.77	.17
Harbor (41')	-	-	.30	.63	.07
Harbor (82')	-	-	.33	.63	.03

608 nm at 'Limit' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	-	.30	.70	-
Ocean (41')	-	-	.23	.60	.17

Table D-3. Proportional Distribution of Scores Across Color-Name Categories for A White Display and Six Narrow-Band Wavelength Displays (Continued)

640 nm at 'Minimum' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	-	.07	.87	.07
Ocean (41')	-	-	-	.97	.03
Harbor (41')	-	-	.03	.93	.03
Harbor (82')	-	-	.03	.97	-

640 nm at 'Clear' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	-	-	.07	.90	.03
Ocean (41')	-	-	.03	.93	.03
Harbor (41')	-	-	.03	.97	-
Harbor (82')	-	-	.03	.93	.03

640 nm at 'Limit' Legibility

	Blue	Green	Yellow	Red	White
Ocean (23')	.07	-	-	.90	.03
Ocean (41')	.03	-	.07	.77	.13

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